EXPERIMENTAL DETERMINATION OF THE PROTECTION FACTORS OF 1:12 AND 1:4 MODELS OF THE KSUNESF BLOCK HOUSE

by

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INTRODUCTION

The problem of providing safe enclosures for the public from fallout radiation resulting from a nuclear explosion involves the analysis of a variety of structures to determine what protection each affords from the radiation. This analysis may be accomplished either theoretically or experimentally. A theoretical method, the "Engineering Manual" method, has been tested extensively and has been shown to give good results in most cases. The experimental methods which simulate a fallout field around a full-sized structure yield better results, but are cumbersome, expensive, and time-consuming. Because of the need to more fully check the theoretical techniques, and because of the disadvantages of using the experimental method on the full-scale buildings, scale models of the structures of interest are being used.

Modeling techniques have been developed to a large extent and have proven to be useful. However, much work remains to be done before model results can be accepted as valid in all cases on their own merits. In this work new and original model data were collected in an effort to help accomplish this goal. A comparison has been made of protection in 1:12 and 1:4 scale models of a concrete block house. The results have been compared with theoretical predictions and with previous studies made in the full-scale structure.

THEORY OF MODELING

The radiation dose distribution inside a structure due to a radioactive field outside in theory should be exactly reproduced in a scale model of the building provided the following two requirements are met:

1. The density of all materials affecting the distribution of radiation must be increased by the same factor by which all dimensions are reduced.
2. The gamma-ray scattering and absorption properties per unit mass of the materials used in the scaled experiment must be the same as those in the full-scale experiment.

These conditions require that the densities of the air and ground as well as the building materials be increased by the same factor that linear dimensions are reduced. In practice the density of these materials can not be increased by a factor of 10, which is necessary if the scale model is to provide much advantage over the full-size structure.

Since it is impractical to satisfy the above requirements, approximations must be made. The first is to replace the building material with one more dense. For this work steel was used to replace concrete since it is high density, inexpensive, and not too different in nuclear properties. This permitted an increase in density about a factor of four. Prior experiments have shown that scaling is still realistic if wall thicknesses are not greater than 10 percent of the average dimensions of a given room.[1] This allowed the total mass of the walls to be increased by another factor of three. Consequently, a scaling factor of 12 was achieved.

There are three possible criteria for selection of model wall thicknesses:

1. The mass thickness of the walls of the full-size structure may be duplicated.
2. The electron density may be maintained.
3. The broad-beam absorption data for slabs may be used.

To illustrate the difference, calculations have shown that 1.69" of iron is necessary to maintain the same mass thickness as an 8" thick, light-weight concrete wall; 1.80" is required if the electron densities are matched; and 1.64" is needed if the broad-beam data are used.

Since the use of the broad-beam data places a heavy dependence on the linearity of the detectors with gamma-ray energy, criterion 3 is seldom chosen for determination of barrier thicknesses.

The average cobalt-60 gamma-ray energy, 1.25 Mev., is representative of the fallout radiation energy spectrum at 1.12 hours after a fission event and is conservative, insofar as shielding calculations are concerned, for fallout energy spectra at other times.[2,3] At this energy Compton scattering is the most probable method of interaction of gamma radiation with a shield. This effect depends upon the electron density of the material. If the barriers of the structure under study were thin, then the model should be constructed so as to match the electron density of the walls of the full-size building. However, the walls of the concrete block house for this work were 69 psf, which is approximately two mean free paths of cobalt-60 gamma rays. Thus, the greater portion of the radiation reaching the interior of the block house has been scattered in the barriers. The attenuation of the scattered radiation is more dependent on the effective atomic number of the shields. Thus, the model barrier thicknesses for this work were calculated on the basis of maintaining the same mass thicknesses present in the full-scale structure. Experimental data supported this decision.[4]

While iron has a smaller electron density than concrete and will transmit more unscattered radiation than the same mass thickness of concrete, this increase is offset by the greater probability of absorption of scattered radiation in iron compared to that of concrete.

EXPERIMENTAL MEASUREMENTS

Description of Models

One-Fourth Scale Model

The steel 1:4 scale model was a replica of a single story concrete block house with a basement (Fig. 11) located at the Kansas State University Nuclear Engineering Shielding Facility (KSUNESF). The external dimensions of the model were kept very close to 1/4 of the full-scale values, while wall, roof, and floor thicknesses were calculated for the model to give the same mass thickness as those of the concrete block house. These values were 1.69" of steel for the walls and 1.35" for the roof and floor. Since slabs of steel with these thicknesses were unavailable commercially, values of 1.75" and 1.375 were used. These compare to 2.0" of iron for the walls and 1.5" for the roof and floor, had the dimensions of the block house simply been scaled down by a factor of four.

Each wall consisted of four slabs of steel (Fig. 2). The floor was three layers thick with each layer made up of four slabs arranged so as to leave an opening into the basement. A trap door was constructed to fill the entrance. Three layers of steel bolted together made up the roof. Each layer consisted of two slabs laid side by side such that cracks in alternate layers were perpendicular. The three layers were bolted together with four 1/2" eye bolts, and two cables were attached through the eyelets. This facilitated the removal of the roof with a fork lift for positioning or retrieving dosimeters. The slabs making up the model walls, roof, and floor were designed and assembled so that there could be no streaming of gamma-rays through cracks or other openings. The model was held together by two 3/4" steel bands strapped around it.

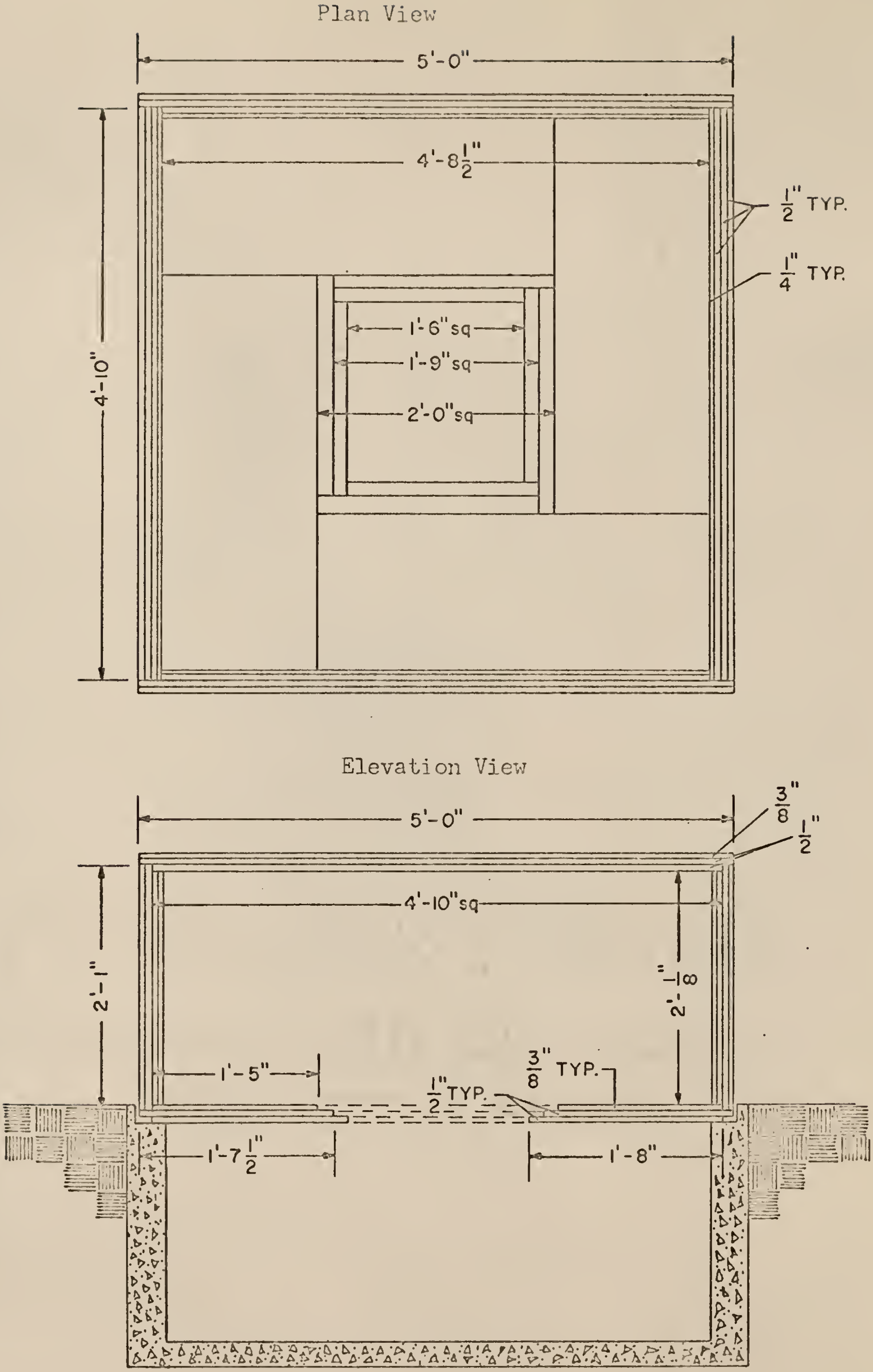


Figure 1. Drawing of the 1:4 model of the KSUNESF block house.

Plan View

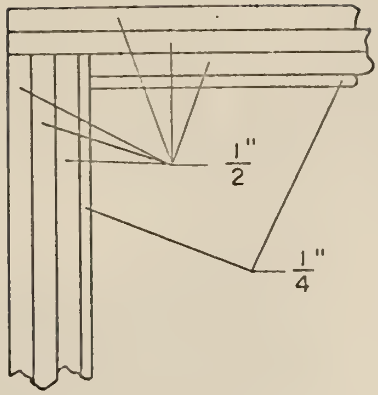


Figure 2. Detail of one corner of the 1:4 model.

Elevation View

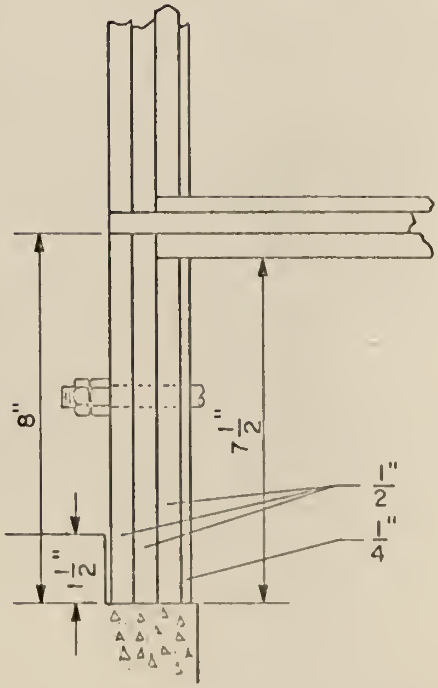


Figure 3. Detail of 1:4 model with floor elevated.

A unique feature of this model was that it could be adapted to simulate a structure having a portion of its basement walls exposed. This was accomplished by jacking-up the entire structure, adding the exposed "basement walls," and then lowering the model down onto the walls. Two steel rods held the four basement walls rigid (Fig. 3).

One-Twelfth Scale Model

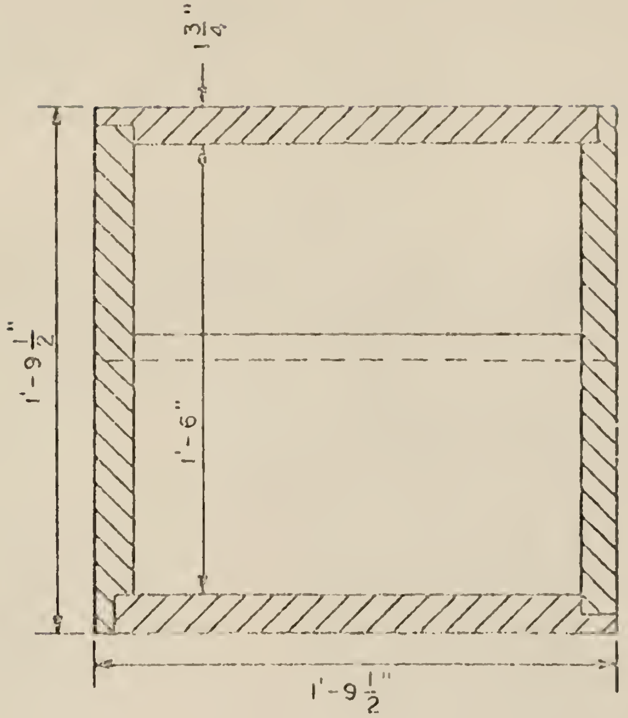
The 1:12 scale model was also constructed of steel and was a replica of the KSUNESF block house. The model dimensions were 1/12 the corresponding dimensions of the full-size structure, except for the thicknesses of the walls, roof, and floor which were calculated for the model to give the same mass thicknesses as those in the block house. It was necessary that 1/8" thick sheets of steel be added to the roof, walls, and floor of the original model in order that the mass thicknesses be closely matched. This made the walls 1.75" and the floor and roof 1.375" thick. See Fig. 4 . As illustrated in Fig. 4, this model could also be adapted to simulate a building with a portion of its basement walls exposed.

Experimental Procedure

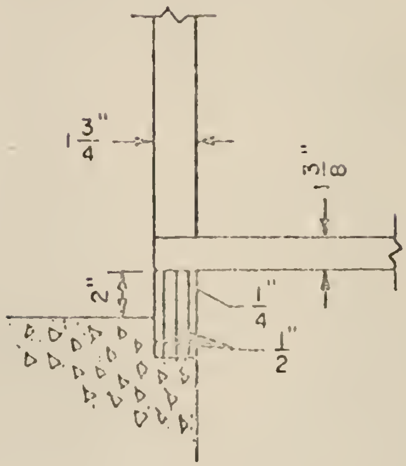
The experimental procedure, much the same for both models, was as follows:

1. Polyethylene tubing was laid around the model in a prescribed fashion to simulate a limited plane of fallout radiation. Figs. 5 and 8 show the tubing layouts for the 1:4 and 1:12 models, respectively.
2. The source container was positioned behind the concrete block house about 50' from the 1:12 model and 80' from the larger model.
3. The pumping system was made ready and one or more dummy source runs were made.
4. Charged dosimeters were enclosed in plastic bags and placed at planned locations in the first floor and basement of the model being

Plan view of model



Detail of model with floor elevated



Elevation View

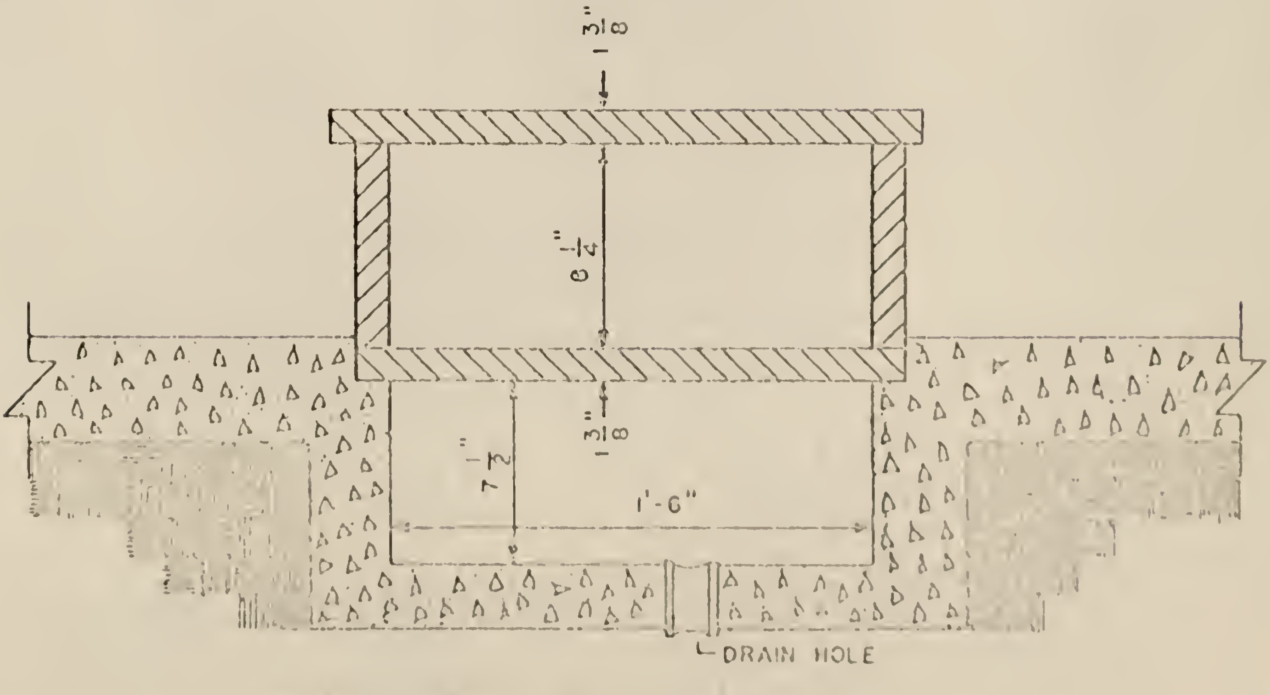


Figure 4. Drawing of the 1:12 model of the KSUNESF block house.

used. This was done during the assembly of the 1:12 model and involved the removal of the roof and trap door of the 1:4 model.

5. A source with an approximate strength of 76 curies was pumped through a section of tubing at a constant speed, so that, since the tubing density was constant in that section, a uniformly distributed fallout field was simulated. Details of the operation of the pumped source system including safety measures are given in Reference 5.
6. The dosimeters were retrieved, unwrapped, read, charged, rewrapped in plastic bags and returned to a position in the model, if another run were to be made.
7. Along with the dosimeter readings, temperature, atmospheric pressure, and the exposure time were recorded.

Measurements and Results

One-Fourth Scale Model

The first series of experimental measurements on the 1:4 model were made with the floor of the model flush with the ground level and with the inner section of tubing (Area II) laid out as shown in Fig. 5. Dosimeters were placed in each corner, on the sides, and in the center of both floors of the model and were positioned nine inches above the floor level - the equivalent of three feet in the full scale structure. See Fig. 6. The 2r dosimeters were used in the first floor and 10 mr dosimeters in the basement. After several preliminary runs had been made, it was found necessary to bake out the 10 mr chambers in an effort to obtain less erratic readings. The experiment was then redone with the baked out chambers in the basement. This time more consistent results were observed as shown by the raw data in Table F-5.

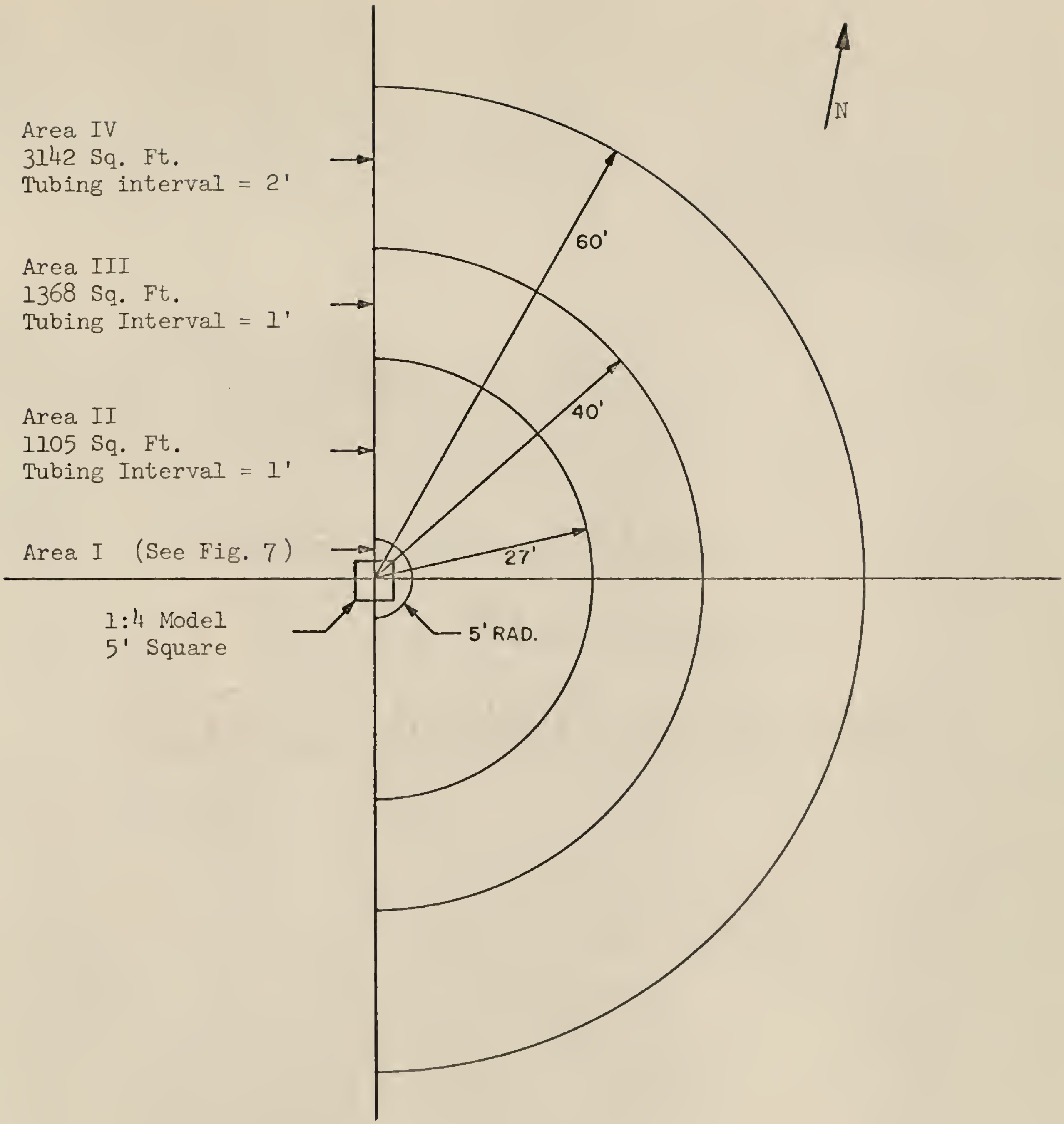


Figure 5. Tubing layout for 1:4 model.

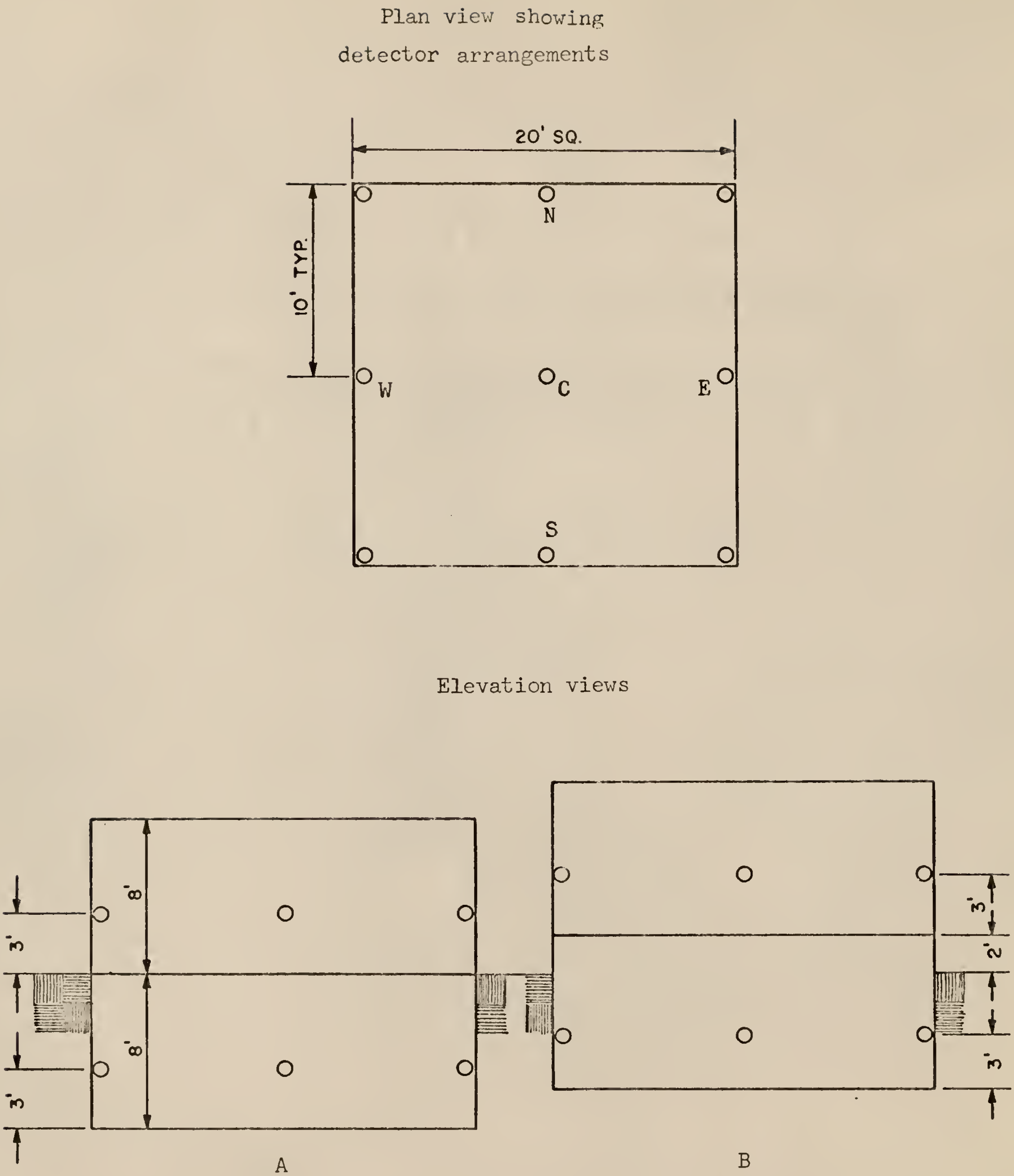


Figure 6. Drawing showing the detector locations with the basement submerged (A) and with the basement partially exposed (B).

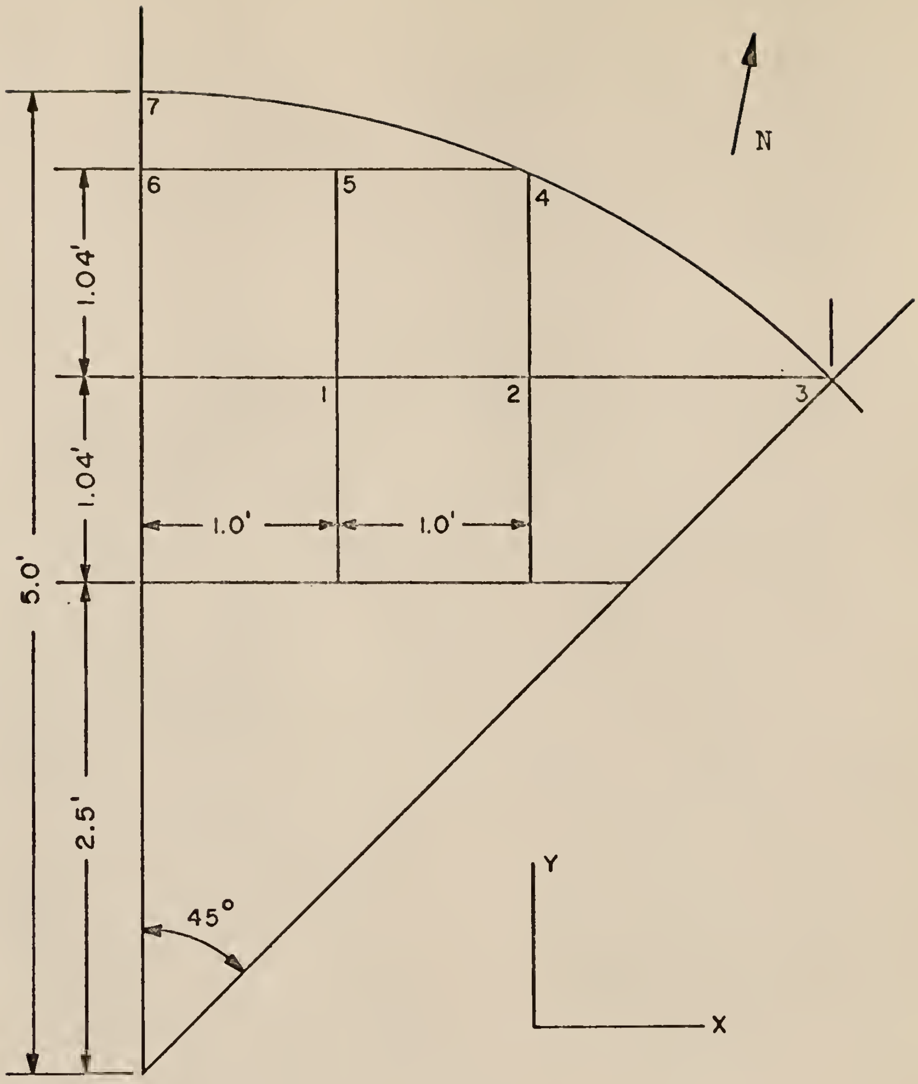
The first run with tubing Area III (27'-40') and the model floor flush with the ground level was done with 2r dosimeters in the first floor and 10 mr dosimeters in the basement. Such low readings were obtained with the 2r dosimeters that they were replaced by 200 mr chambers in subsequent runs. These data are reproduced in Table F-6.

For the last tubing area and the same model configuration, data could only be taken on the first floor (Table F-8) since it would have required an excessive exposure time to get satisfactory results in the basement.

The contamination in Area I was simulated by a series of point sources. As shown in Fig. 7, a 45° sector out to a radius of five feet was divided into seven smaller areas. A point source was placed on the centroid of each area in turn until all seven areas had been covered. The exposure time for each area was calculated so as to maintain a uniform average source density.

As might be expected, a considerable amount of radiation reached the dosimeters in the basement directly by penetrating the concrete and earth adjacent to the model. Since no provisions were made for this ground penetration in the theoretical calculations[6], and since the contribution was comparatively small in the full-scale block house, it was necessary to eliminate this contribution. This was done by performing the experiment with the point source just described except that now the point source was covered with a minimum of four inches of lead. This eliminated practically all radiation in the basement except that which penetrated the concrete and ground. The ground contribution from the field farther out than five feet from the center of the model was negligible.

With the conclusion of the first series of experiments, the model was elevated six inches so as to simulate a block house with two feet of its basement walls exposed, and the above experiments were repeated. Even though the first floor of the model was elevated six inches and nothing was placed in the floor



Subarea No.	Area (ft^2)	Centroid $\bar{x}$	Centroid $\bar{y}$
1	1.04	0.50	3.02
2	1.04	1.50	3.02
3	1.04	2.60	3.17
4	1.04	0.50	4.06
5	1.04	1.50	4.06
6	0.90	2.56	3.96
7	0.55	0.79	4.85

Figure 7. Area I of the 1:4 Model Field

TABLE 1. NORMALIZED DOSES (R/HR PER CURIE/FT^2) FOR THE 1:4 MODEL

	Position	Ground Penetration	Area I (0-5')	Area II (5'-27')	Area III (27'-40')	Area IV (40'-60')	Total
Basement	Floor Flush						
	Side	1.68 ± 0.0170	2.36 ± 0.0229	0.192 ± 0.00427	0.0509 ± 0.00127		0.928 ± 0.0289
	Corner	1.28 ± 0.0153	1.80 ± 0.0213	0.129 ± 0.00298	0.0301 ± 0.00120		0.675 ± 0.0264
	Center	3.12 ± 0.0525	4.20 ± 0.0702	0.354 ± 0.00992	0.0936 ± 0.00326		1.53 ± 0.0883
	Floor Elevated						
	Side	2.59 ± 0.0290	5.32 ± 0.116	1.54 ± 0.0231	0.334 ± 0.00643	0.293 ± 0.00578	4.89 ± 0.122
	Corner	3.09 ± 0.0461	4.51 ± 0.132	0.910 ± 0.0187	0.198 ± 0.00460	0.178 ± 0.00424	2.71 ± 0.144
	Center	2.97 ± 0.0565	8.63 ± 0.305	2.98 ± 0.0638	0.625 ± 0.0206	0.566 ± 0.0193	9.82 ± 0.318
First Floor	Floor Flush						
	Side		12.0 ± 0.286	24.7 ± 0.580	5.38 ± 0.0609	5.02 ± 0.060	47.1 ± 0.652
	Corner		13.8 ± 0.314	31.7 ± 0.728	6.36 ± 0.0736	6.04 ± 0.069	57.9 ± 0.799
	Center		11.7 ± 0.483	26.7 ± 1.33	5.95 ± 0.132	5.47 ± 0.131	49.8 ± 1.43
	Floor Elevated						
	Side		4.61 ± 0.173	25.7 ± 0.633	5.75 ± 0.0664	5.24 ± 0.0628	41.3 ± 0.662
	Corner		5.78 ± 0.219	33.0 ± 0.780	6.73 ± 0.0737	6.38 ± 0.0762	51.8 ± 0.817
	Center		2.95 ± 0.0491	28.8 ± 1.38	6.31 ± 0.130	5.76 ± 0.133	43.8 ± 1.39

of the basement to take up the additional six inches created, the basement was considered to be the same size. Thus, the dosimeters in the basement were raised an additional six inches to maintain the three-foot level in the full-scale building.

As was the case with the first series of experiments, the source exposure times were adjusted insofar as possible to maintain dosimeter readings between 20 and 80 percent of their full-scale values. The raw data collected from experiments on the 1:4 model begin on Page 59 of Appendix F. The reduced data and protection factors calculated therefrom appear in Tables 1 and 3, respectively.

One-Twelfth Scale Model

The tubing for the 1:12 model was laid completely around the model and in two sections, each representing an annular strip of radioactive fallout. The field closest to the model, Area I, was represented by a series of point sources over a sector including 1/8 of the perimeter of the model. This area was subdivided into seven smaller areas as shown in Fig. 9, and the experiment was conducted as outlined for the 1:4 model. Since the 1:12 model was easily assembled and disassembled, each series of experiments were performed first with the model floor flush with the ground level and then with the floor elevated.

Only the 200 mr and 2r dosimeters were used with the 1:12 model since they were the smallest physical size available. The 200 mr dosimeters were generally used in the basement while the 2r dosimeters were required for the first floor measurements. Both types were positioned in the same relative locations as in the 1:4 model; that is, three inches from the floors in the corners, sides, and center of the model.

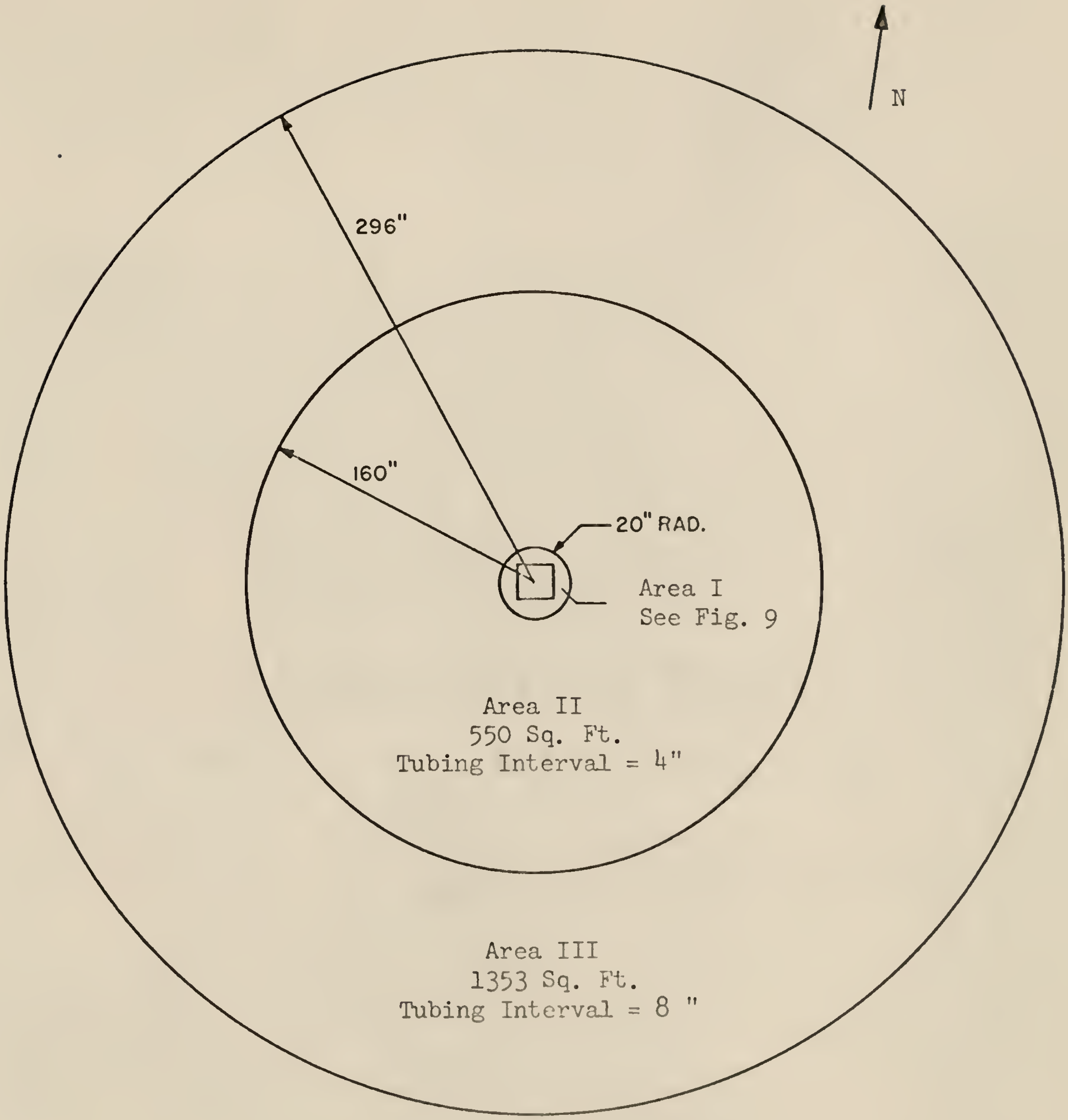


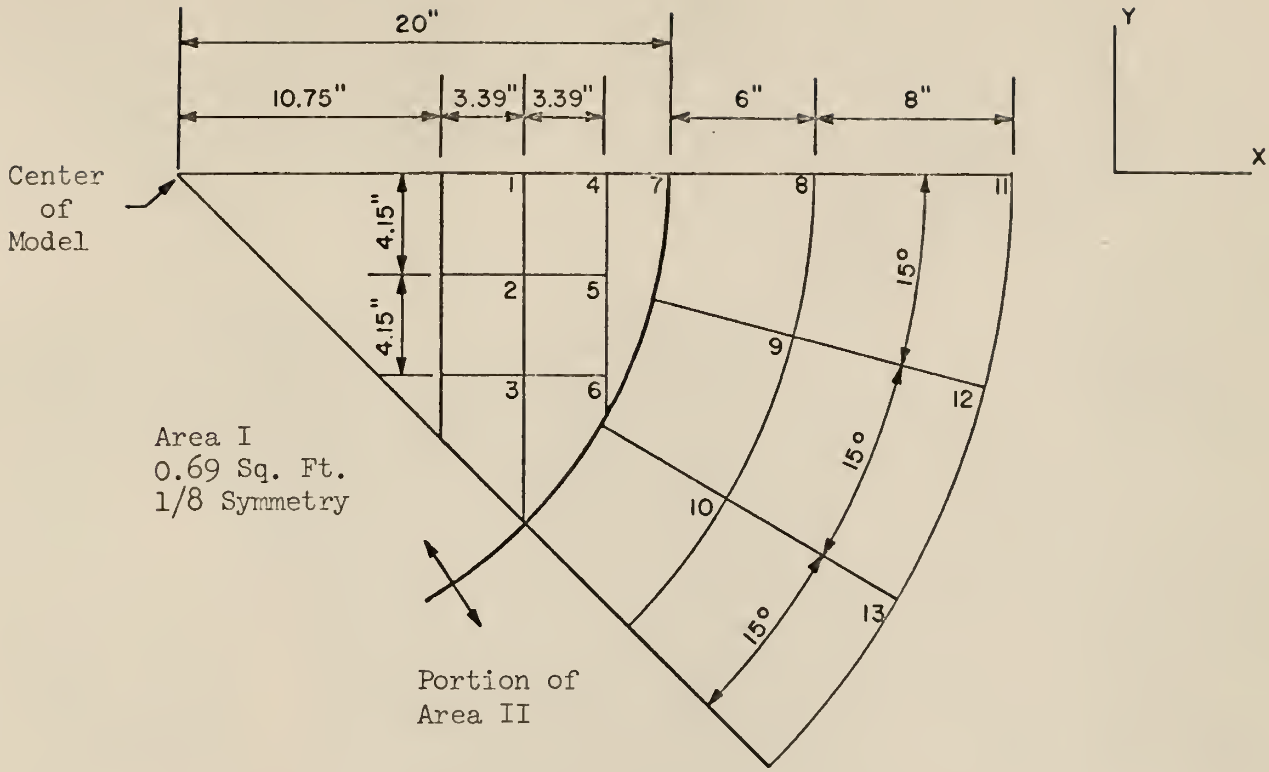
Figure 8. Tubing layout for the 1: 12 model.

Some difficulty was experienced collecting data from Area III with the basement of the model completely underground. As can be seen from Table F-26, lower than desirable doses were accumulated in the basement in spite of the lengthy exposure times which averaged about three hours for each run.

Since these and several other runs were rather long, all three types of dosimeters were checked to determine the extent of leakage. It was found that the 200 mr and 2r dosimeters did not drift significantly in 24 hours. The 10 mr chambers, although not as stable, did not drift enough to require corrections to the experimental data.

As with the 1:4 model, a great portion of the dose received in the basement from the field near the model came from radiation penetrating the ground and concrete. This is pointed out in Table F-19. The ground penetration was determined using the same procedure as that used for the larger model. However, it was necessary to take ground penetration into account not only from Area I, but also from a portion of Area II (Fig. 9).

The raw data taken on the 1:12 model begin on Page 77 of Appendix F . The normalized data are given in Table 2.



Subarea No.	Area (in^2)	Centroid $\bar{x}$	Centroid $-\bar{y}$
1	14.07	12.45	2.08
2	14.07	12.45	6.23
3	14.07	12.67	10.61
4	14.07	15.84	2.08
5	14.07	15.84	6.23
6	13.06	15.28	10.31
7	15.60	19.07	3.75
8	36.13	22.87	3.01
9	36.13	31.31	8.83
10	36.13	18.30	14.04
11	62.83	29.83	3.93
12	62.83	27.80	11.52
13	62.83	23.87	18.32

Figure 9. Area I of the 1:12 model field and the portion of Area II from which ground penetration was obtained.

TABLE 2. NORMALIZED DOSES (R/HR PER CURIES/FT^2) FOR THE 1:12 MODEL

	Position	Ground Penetration I (-20")	Ground Penetration II (20"-34")	Area I (-20")	Area II (20"-160")	Area III* (160"-296")	Total
Basement	Floor Flush						
	Side	8.73 ± 0.256	0.768 ± 0.00758	9.43 ± 0.313	1.38 ± 0.0193	0.0403 ± 0.00120	1.35 ± 0.405
	Corner	7.69 ± 0.302	1.33 ± 0.0580	8.78 ± 0.334	1.61 ± 0.0232	0.0264 ± 0.00124	1.40 ± 0.454
	Center	9.20 ± 0.478	1.01 ± 0.0171	10.6 ± 0.507	2.04 ± 0.0494	0.0646 ± 0.00307	2.48 ± 0.698
	Floor Elevated						
	Side	13.6 ± 0.440	0.890 ± 0.0208	16.9 ± 0.430	3.26 ± 0.0323	0.379 ± 0.00578	6.02 ± 0.616
	Corner	17.0 ± 0.527	1.57 ± 0.0678	19.7 ± 0.509	3.32 ± 0.0375	0.247 ± 0.00573	4.69 ± 0.737
	Center	5.66 ± 0.124	0.968 ± 0.0161	11.7 ± 0.486	4.88 ± 0.0946	0.620 ± 0.0167	10.6 ± 0.511
First Floor	Floor Flush						
	Side			17.8 ± 0.420	32.7 ± 0.657	6.19 ± 0.0698	56.6 ± 0.783
	Corner			18.0 ± 0.457	39.4 ± 0.699	6.91 ± 0.0781	64.3 ± 0.839
	Center			14.4 ± 0.542	36.5 ± 1.42	7.36 ± 0.165	58.2 ± 1.53
	Floor Elevated						
	Side			5.01 ± 0.134	34.4 ± 0.684	8.98 ± 0.287	48.4 ± 0.754
	Corner			6.19 ± 0.211	40.7 ± 0.707	9.80 ± 0.334	56.7 ± 0.810
	Center			2.69 ± 0.0713	40.0 ± 1.39	10.4 ± 0.607	53.1 ± 0.753

*The field dimensions for the floor flush, basement case were 160"-248" rather than 160"-296".

SUMMARY

The normalized dose rates in the last column of Tables 1 and 2 give the experimental data in their final form. The standard deviations associated with the experimental results are, for the most part, small. The largest uncertainties occur in the data taken in the basement of the 1:12 model and range from 7.37% to 36.0%. Elsewhere the standard deviations are less than 6.04% in the 1:12 model and do not at any position exceed 7.56% in the 1:4 model.

In order to determine the protection factors for the various positions in the two models, it was necessary to first scale up the model data to correspond to that of a full-size structure, then make the far-field corrections as described in Appendix D.* An error of 5% was assumed to be made in performing these operations. The protection factors found in Table 3 were found by dividing the scaled-up corrected numbers into the free-field dose rate at three feet (485 ± 11 r/hr per curie/ft^2). As shown the protection factors for the two models agree within their standard deviations except in the corners of the basement.

Also found in Table 3 are the protection factors calculated using the "Engineering Manual" method (Appendix E) and those determined experimentally from the full-scale block house during summer institutes. Data collected during the institutes can be compared with the average model results in five of the twelve cases. The comparison ranges from 28% in the center to 29% in the corner of the first floor and 73% to 118% for the same positions in the basement. Model data gave the higher results on the first floor with the opposite being true in the basement.

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*Revisions have been made in the curves used in reducing the model data since the above results were obtained. The basement calculations are expected to be affected the most.

The engineering method was used to calculate the protection factors for each location in which data was collected in the models. On the first floor the theoretical calculations were conservative by about 30% when compared to the model data. As expected the two compared most favorably in the center position.

The engineering method has consistently failed to accurately predict experimental findings in basement positions. One of several methods suggested for improving these calculations was developed by R. L. French.[14] Unlike the others, however, French's method requires no charts additional to the ones in the "Engineering Manual" and is still comparable in accuracy to the other methods. The engineering method basement calculations listed in Table 3 were obtained with the aid of French's method. A brief outline of the use of this method is given in Appendix E. After the adjustments, theoretical calculations were within 25% of the model data in the center position and 50% in the corner when a portion of the basement walls were exposed. The comparison dropped to 43% and 158% for the same positions when the basement was fully submerged.

The model results and theoretical calculations show that the safest location in the structure is in the corners of the basement. The results also show that in this case the protection factors in a fully submerged basement are greater by about a factor of five than those for a basement with partially exposed walls.

One of the more important areas for improvement lies in the detection system. It is expected that since the physical size of some of the dosimeters used were substantial compared to the dimensions of the room, the measurements represent an average dose rate over a volume, rather than at a point. New detection systems, such as thermoluminescent dosimetry, should be considered. Possibly another significant factor is the absorption in the polyethylene tubing between the model and source of radiation emitted in a direction almost parallel

to the ground. several effects such as the source anisotropy, source energy degradation, and other errors introduced by the approximation of a point source with an encapsulated volumetric source probably affected the results to a lesser extent.

TABLE 3. A COMPARISON OF THE PROTECTION FACTORS OBTAINED EXPERIMENTALLY FROM THE MODELS AND FULL-SCALE BLOCK HOUSE WITH THE ENGINEERING MANUAL CALCULATIONS

	1:12 Model	1:4 Model	Engineering Manual	Block House Results 1965 Institute	1963 Institute	1962 Institute
Floor Flush; Basement						
Side	379 ± 121 (32.0)*	479 ± 30.0 (6.18)	731			
Corner	379 ± 136 (36.0)	682 ± 45.0 (6.63)	1370	1136	1180	
Center	208 ± 63 (30.4)	286 ± 22.0 (7.56)	353	455	460	370
Floor Elevated; Basement						
Side	84.1 ± 10.1 (12.0)	95.1 ± 5.7 (5.99)	118			
Corner	112 ± 20.0 (17.8)	173 ± 13.0 (7.43)	212			
Center	46.7 ± 3.4 (7.37)	46.6 ± 2.9 (6.28)	58.1			
Floor Flush; First Floor						
Side	8.57 ± 0.49 (5.66)	9.19 ± 0.52 (5.63)	6.25	5.6		4.14
Corner	7.75 ± 0.44 (5.65)	7.71 ± 0.44 (5.64)	5.92	5.5	5.56	
Center	7.93 ± 0.48 (6.04)	8.37 ± 0.50 (6.02)	6.40	6.1	5.9	5.7
Floor Elevated; First Floor						
Side	9.40 ± 0.53 (5.68)	10.1 ± 0.57 (5.66)	6.89			
Corner	8.35 ± 0.47 (5.66)	8.36 ± 0.47 (5.67)	6.63			
Center	8.22 ± 0.46 (5.64)	9.14 ± 0.56 (6.09)	7.18			

* The numbers in parentheses are the standard deviations in per cent.

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APPENDIX A

FACILITY AND EQUIPMENT

The experimental portion of this work was performed at the Kansas State University Nuclear Engineering Shielding Facility (KSUNESF) located about six miles west of campus. The principal facilities are as indicated in Fig. 10 and include a full-scale block house, foxhole, 5,000 square foot concrete slab, 1:12 and 1:4 scale models of the block house. The equipment available includes a pumped source fallout simulation system, gamma-ray projector, sources ranging up to about 80 curies, fork lift, radiation survey meters, dosimeters, Gamm-Alarm, and other instrumentation.

The concrete block house from which the models were designed (Fig. 11) was constructed of lightweight concrete having an average density of 103 pounds per cubic foot. The roof and floor were made of pre-cast, pre-stressed concrete slabs while the walls were concrete blocks stacked without mortar.

Many precautions were taken to assure the protection of all personnel from radiation exposure. The experiments were performed within the rules and regulations of the KSU Radiation Safety Committee.

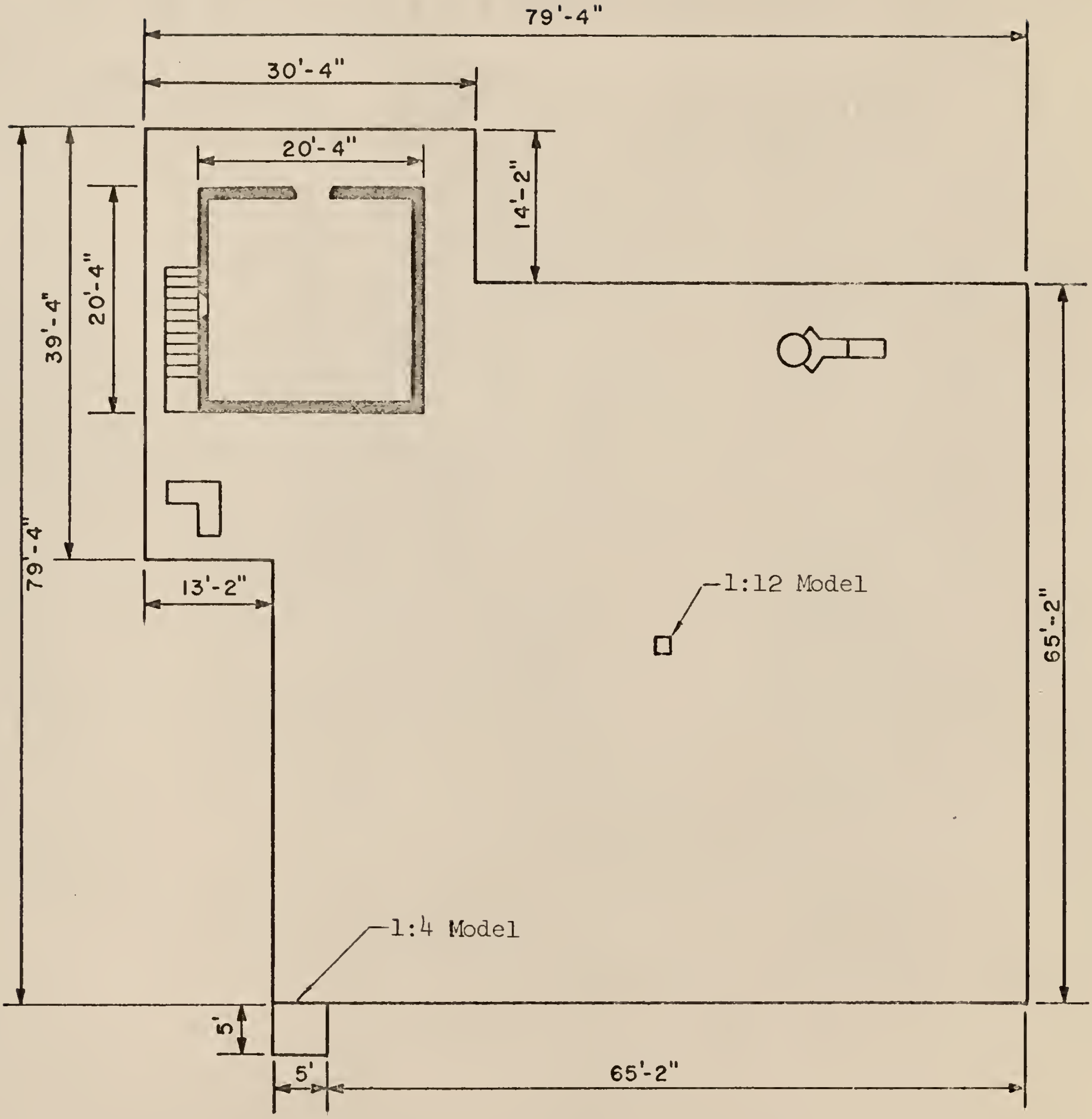
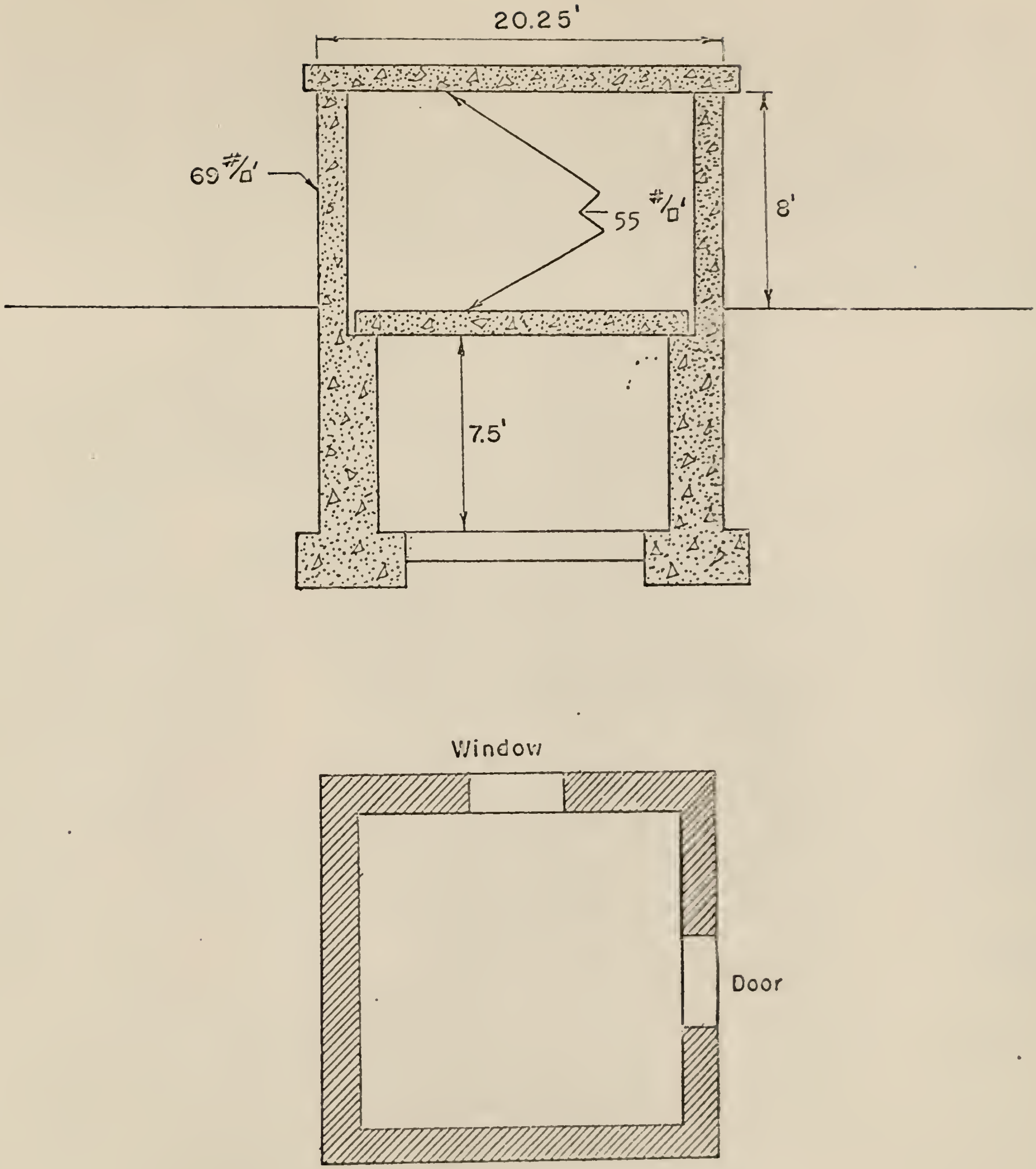


Figure 10. Plan of shielding facilities.



Sketch of Block House

Fig. 11

APPENDIX B

DATA REDUCTION

In this section, a resume is given of the treatment of the data and associated error terms from the readings of the charger-readers to the calculation of the protection factors. To better illustrate the techniques involved in reducing the data, one set (Table B-1) will be taken as an example and all operations performed on it.

Since these data were collected with 2r dosimeters which are not hermetically sealed, a correction was applied to standardize the data to 22°C and 760 mm Hg. The correction factor β was calculated from the following expression:

$$\beta = \frac{\left[273.0 + 0.555(T - 32.0)\right] \; 760.0}{(295.0)(25.40) \; P} \qquad \text{(B-1)}$$

where T is the temperature in degrees Fahrenheit and P is the atmospheric pressure in inches of mercury. The same correction was made on the data obtained with the 10 mr dosimeters, but not data accumulated with 200 mr dosimeters since they were hermetically sealed. Table B-2 gives the sample data after being normalized to a common temperature and pressure. Program 1 was used to perform the above corrections.

Since the exposure doses were taken in terms of meter readings in microamperes (μa), it was necessary to relate these readings to the true dose received. As described below, a calibration line was developed for this purpose for each dosimeter with the aid of regression analysis. In addition, the error associated with each exposure dose was determined using regression analysis. The data

shown in Table B-3 are the resultant exposure doses and error limits obtained from the calibration lines. Program 6 performed this function.

The doses were next normalized to r/hr per curie/ft^2 using the expression

$$D_c = \frac{A}{CT} D, \tag{B-2}$$

where D_c = normalized exposure dose in $\frac{r/hr}{curies/ft^2}$,

A = area of contaminated field in ft^2,

C = strength of the source in curies,

T = exposure time in hours,

and D = dose received by detector in roentgens.

Table B-4 shows the normalized data arranged according to location in the model.

Since these data were taken using a section of tubing that completely encircled the model, the normalized doses from the corners, sides, and center were simply averaged to obtain one dose for each of the three detector locations. In other instances, the simulated fallout field covered only 1/2 or 1/8 of the perimeter of the model. A different averaging procedure was followed for these cases. First, the three, four, or five runs that were made were averaged position by position into one set of data. Then, for the 1/2 symmetry case, the results of all four corner measurements were added, as were the results from the side locations, and the sums divided by two. The dose received in the center of the model was multiplied by two. When only 1/8 symmetry was used, the four corner values and side dose rates were added and multiplied by two. The dose rate received in the center was, of course, multiplied by eight. Table B-5 summarizes the reduced sample set of data.

Each of the other sets of data was reduced as demonstrated above. The results are given in Table 1 for the 1:4 model and Table 2 for the 1:12 model.

The normalized doses for each annulus of the finite contaminated field were added for each model configuration. The model data were then scaled up to the full-size structure and the far-field corrections made using a new method developed by Kaplan et. al.[4], which is described in Appendix D. The protection factors were calculated by dividing the free-field dose rate at three feet (485 ± 11 r/hr per curie/ft^2)[4] by the experimental doses (Table 3).

The error analysis proceeded as follows: Confidence limits for each dose were obtained with the dose from the calibration line. When the experimental measurements were normalized to r/hr per curie/ft^2, the error terms were also normalized. Since the source strength was not known exactly, the standard deviation associated with it had to be reckoned with. If we let ϵ_1 and ϵ_2 represent the statistically independent errors of D and C respectively, then the error induced in D_c, denoted by δ, as a result of the errors ϵ_1 and ϵ_2 has a variance equal to

$$V(\delta) = \left(\frac{AD}{CT}\right)^2 \left[\frac{V(\epsilon_1)}{D^2} + \frac{V(\epsilon_2)}{C^2}\right] . \qquad \text{(B-3)}$$

Sample calculations showed that the errors associated with the exposure times and contaminated areas were small compared to the errors inherent in the source strength values and experimental doses. When "n" normalized doses were averaged, the variance of the resultant average dose was found from

$$V(D_{ave}) = \frac{V(D_1) + V(D_2) + \ldots + V(D_n)}{n^2} . \qquad \text{(B-4)}$$

TABLE B-1. RAW DATA (μa)

Floor Elevated First Floor		Area II (20"-160") A=550 ft^2				1:12 Model S=77.84 Curies					
Dosimeter Number	Run 1		Run 2		Run 3		Run 4				
	Pos.	t=12.37 min T=74° F P=28.73 in. Hg	Pos.	t=11.98 T=74 P=28.72	Pos.	t=12.25 T=73 P=28.71	Pos.	t=12.03 T=76 P=28.75			
147	NW	49.0	NW	49.5	C	47.0	NW	50.5			
134	S	42.5	NE	49.0	N	44.5	W	41.0			
137	SW	49.5	SE	49.0	W	43.5	S	41.5			
135	N	45.5	C	49.0	SW	50.5	N	45.5			
140	W	46.0	E	43.0	NE	53.0	SE	49.0			
151	C	49.0	W	44.0	SE	51.5	C	49.6			
150	NE	50.0	SW	50.5	S	45.0	SW	48.5			
145	E	44.0	N	44.0	NW	50.0	NE	51.0			
144	SE	49.0	S	43.0	E	44.0	E	43.5			

TABLE B-2. DATA NORMALIZED TO 22°C AND 760 mm Hg. (μa)

Floor Elevated First Floor		Area II (20"-160") A=550 ft^2				1:12 Model S=77.84 Curies		
Dos. Number	Run 1		Run 2		Run 3		Run 4	
	Pos.	t=12.37 min	Pos.	t=11.98	Pos.	t=12.25	Pos.	t=12.03
147	NW	51.3	NW	51.8	C	49.1	NW	53.0
134	S	44.6	NE	51.3	N	46.5	W	43.0
137	SW	51.8	SE	51.3	W	45.4	S	43.5
135	N	47.6	C	51.3	SW	52.8	N	47.7
140	W	48.1	E	45.0	NE	55.4	SE	51.4
151	C	51.3	W	46.0	SE	53.8	C	52.0
150	NE	52.3	SW	52.8	S	47.0	SW	50.9
145	E	46.0	N	46.0	NW	52.2	NE	53.5
144	SE	51.3	S	45.0	E	46.0	E	45.6

TABLE B-3. DATA AS INTERPRETED FROM CALIBRATION LINES (R)

Floor Elevated First Floor		Area II (20"-160") A=550 ft^2		1:12 Model S=77.84 Curies
	Run 1 t=12.37 min	Run 2 t=11.98	Run 3 t=12.25	Run 4 t=12.03
147	NW 1.15 ± 0.0738	NW 1.16 ± 0.0741	C 1.08 ± 0.0726	NW 1.19 ± 0.0738
134	S 0.969 ± 0.0680	NE 1.17 ± 0.0714	N 1.03 ± 0.0689	W 0.928 ± 0.0673
137	SW 1.13 ± 0.0793	SE 1.11 ± 0.0791	W 0.956 ± 0.0767	S 0.903 ± 0.0756
135	N 1.04 ± 0.0735	C 1.13 ± 0.0753	SW 1.18 ± 0.0761	N 1.04 ± 0.0735
140	W 1.02 ± 0.0817	E 0.942 ± 0.0807	NE 1.21 ± 0.0847	SE 1.11 ± 0.0830
151	C 1.17 ± 0.0778	W 1.02 ± 0.0753	SE 1.24 ± 0.0792	C 1.19 ± 0.0782
150	NE 1.19 ± 0.0722	SW 1.20 ± 0.0725	S 1.04 ± 0.0695	SW 1.15 ± 0.0714
145	E 0.993 ± 0.0767	N 0.993 ± 0.0768	NW 1.17 ± 0.0795	NE 1.20 ± 0.0802
144	SE 1.12 ± 0.0830	S 0.951 ± 0.0805	E 0.978 ± 0.0808	E 0.968 ± 0.0807

TABLE B-4. DATA NORMALIZED TO R/HR PER CURIE/FT^2

Floor Elevated First Floor		Area II (20"-160") A=550 ft^2		1:12 Model S=77.84 Curies
Pos.	Run 1	Run 2	Run 3	Run 4
S	33.2 ± 2.43	33.6 ± 2.94	36.0 ± 2.52	31.9 ± 2.76
E	34.0 ± 2.72	33.4 ± 2.94.	33.8 ± 2.89	34.1 ± 2.93
N	34.5 ± 2.63	35.1 ± 2.82	35.6 ± 2.50	36.7 ± 2.70
W	35.1 ± 2.90	36.2 ± 2.77	33.1 ± 2.74	32.7 ± 2.47
SE	38.5 ± 2.96	39.5 ± 2.92	43.0 ± 2.89	39.1 ± 3.04
SW	38.7 ± 2.84	42.5 ± 2.71	40.8 ± 2.77	40.4 ± 2.66
NW	39.2 ± 2.66	41.1 ± 2.77	40.2 ± 2.87	42.0 ± 2.78
NE	40.6 ± 2.62	41.2 ± 2.67	42.0 ± 3.06	42.1 ± 2.96
C	40.2 ± 2.80	40.3 ± 2.80	37.5 ± 2.64	42.0 ± 2.90

TABLE B-5. AVERAGE NORMALIZED DATA (R/HR PER CURIE/FT^2) FOR THE THREE DETECTOR LOCATIONS

Floor Elevated First Floor	Area II (20"-160") A=550 ft^2	1:12 Model S=77.84 Curies
Location	Normalized Data	
Side	34.4 ± 0.684	
Corner	40.7 ± 0.707	
Center	40.0 ± 1.39	

APPENDIX C

DOSIMETER CALIBRATION

Three types of dosimeters were used in this study. The Landsverk 2-roentgen (L-81) dosimeters were used whenever possible because of their small physical size. As small as they were (1.5" long, 0.5" dia.), when scaled up a factor of 12, they would represent a detector 1.5' long and 0.5' diameter. Conversely, the Victoreen 10 milliroentgen (mr) dosimeters were used only when necessary in the 1:4 model and not at all in the 1:12 model because of their size (2.5" long, 2" dia.). A Technical Operations charger-reader was used for each of these types of dosimeters. The third and most frequently utilized type was the Bendix 200 mr dosimeter. A Jordan Electronics portable charger-reader was used with these.

For each of the 2r and 10 mr dosimeters a calibration line was developed to determine the relationship between the reading in microamperes (μa) on the Technical Operation charger-reader and the exposure dose. A calibration line was also developed for each of the 200 mr dosimeters since the reading in mr did not necessarily correspond to the true exposure dose.

The experimental doses were obtained by exposing the detectors to a known quantity of cobalt-60 radiation for varying periods of time. A calibration stand was constructed so that a constant source-to-detector distance could be maintained and so that the effect of scattering from the ground could be minimized.

The theoretical dose rates were calculated using the following equation:

$$D = \frac{KSB_1B_2e^{-\mu x}}{4\pi X^2} , \qquad (C-1)$$

in which D = exposure dose rate in milliroentgens per hour,

K = conversion factor $\left[(mr/hr)/(mc/cm^2)\right]$ at 22 C, 760 mm Hg.; = $1.71 \times 10^5 \frac{mr/hr}{mc/cm^2}$,

S = strength of the cobalt-60 source in millicuries,

B_1 = buildup factor due to air scattering,[18]

B_2 = buildup factor due to ground scattering,

μ = total gamma-ray attenuation coefficient (cm^{-1}) for 1.25 Mev. gamma-rays at 22 C, 760 mm of Hg; = 6.79×10^{-5} cm^{-1}[7], and

X = source to detector distance in centimeters.

As an example, the theoretical dose rate for the 200 mr dosimeters will be calculated. If S_i is the strength of the cobalt-60 source in millicuries on a given date, t is the time in years from the date corresponding to S_i to the date the calibration work was done, and $t_{1/2}$ is the half-life of cobalt-60 in years, then the source strength on the date of the experiment is

$$S = S_i \exp(-0.693\, t/t_{1/2}). \qquad (C-2)$$

Substituting in the appropriate values gives

$$S = (265 \text{ mc})^* \exp\left[-(0.693)(1.08)/(5.27)\right] \qquad (C-3)$$

$$= 230 \text{ mc}.$$

-----

*This is the strength of the source on August 10, 1965, as determined from a calibrated Victoreen Model 570-R Meter.[8] The other sources used in this work were calibrated similarly.

The buildup factor due to air scattering for $r = \mu x = 6.21 \times 10^{-3}$ is

$$B_1 = 1.0 + (0.92)(6.21 \times 10^{-3})\, e^{0.0632(6.21 \times 10^{-3})} \qquad (C - 4)$$

$$= 1.0057$$

The source and dosimeters were elevated 5' 2" above a concrete floor and were 3' 0" apart. Using these factors the buildup factor due to ground scattering, B_2, was found from Clark and Batter[9] to be 1.0069.

Finally,

$$e^{-\mu x} = e^{-r} = 0.994$$

We now have all the parameters necessary to find the theoretical dose rate.

$$D\left(\frac{mr}{hr}\right) = \frac{(1.71 \times 10^5)(230)(1.0057)(1.00686)(0.994)}{4(3.1416)(91.4)^2} = 376 \frac{mr}{hr} \qquad (C - 5)$$

Similarly for the 10 mr dosimeters $D = 49.4 \frac{mr}{hr}$ and $D = 3.20 \frac{r}{hr}$ for the 2r dosimeters.

The theoretical doses were plotted on the abscissa versus the experimental values on the ordinate. These points were then fitted with a least squares line which, for the 200 mr and 10 mr dosimeters, passed through the origin. For reasons to be discussed later, two lines, one of which passed through the origin, were necessary to describe the 2r calibration lines. Since the strength of each source used in the calibration work had a constant percentage error associated with it, the theoretical doses included a constant error term. Thus, when the least squares fit of the data or regression line was developed, the Berkson model[10] was applied to take into account the constant error in the X values.

Since it was desired to determine the theoretical dose from the experimental reading, a regression line in reverse through the origin (Eq. C -6) was found for each 200 mr and 10 mr dosimeter.

$$X = \frac{\bar{y}}{b} \pm \frac{ts'}{b} \left(\frac{1}{m} + \frac{\bar{y}'^2}{b^2 \; \Sigma x_i^2} \right)^{1/2} , \qquad (C - 6)$$

where $\bar{y}$ is the mean of m new experimental observations; b is the slope of the line; s' is an estimate of the standard deviation including the error associated with the calibration source; and t is the Student's t-distribution.[11] For a detailed presentation of regression analysis, see <u>Statistical Theory and Methodology in Science and Engineering</u> by K. A. Brownlee.[12] The constants for the regression lines for the 200 mr and 10 mr dosimeters are tabulated below. The value of t for 68 percent confidence (one standard deviation) and 30 degrees of freedom is 1.01.

The 10 mr and 200 mr dosimeters were essentially linear with dose. This was not the case for the 2r dosimeters. The calibration curve for each of the 2r dosimeters may be represented by two regression lines, one of which passes through the origin. This characteristic is a consequence of the dosimeter's construction. Unlike the 200 mr and 10 mr dosimeters which are a single co-axial capacitor, the 2r detectors have a center electrode made in two sections which are not in contact except during the charging and reading of the dosimeter. One section is a short pin centered in a flexible diaphram at one end of the dosimeter. When the dosimeter is being charged or read, this end of the dosimeter is pressed into the charger-reader receptacle until the pin makes contact with the larger central electrode. Both electrodes are then fully charged. When the dosimeter is withdrawn, the pin loses contact with the larger electrode,

and then there are essentially two dosimeters in the same shell. This is the reason why two regression lines, rather than one, are necessary for the description of each 2r calibration curve.

The portion of the curve passing through zero was fitted with a least squares line in a manner similar to that used for the 200 mr and 10 mr dosimeters. The upper portion of the curve was represented by a regression line in reverse using the following expression:

$$X = \bar{x} + \frac{\bar{y}-a}{b} \pm \frac{ts'}{b}\left[\left(\frac{1}{m} + \frac{1}{k}\right) + \frac{(\bar{y}-a)^2}{b^2\ \Sigma(x_i-\bar{x})^2}\right]^{1/2}, \qquad (C-7)$$

where k is the number of observations (x_i, y_i), a is $\Sigma y_i/k$, and the other parameters are as explained earlier. Again, a 68 percent confidence level was used for determining t, which for 17-23 degrees of freedom equals 1.02 (used with Table C-3) and for 27-34 degrees of freedom equals 1.01 (used with Table C-4).

Tables C-3 and C-4 list the constants to be used in Equations C-6 and C-7 , respectively, to obtain the calibration lines for each dosimeter.

TABLE C-1. CONSTANTS FOR 200 MR DOSIMETER REGRESSION LINES

Dosimeter No.	b	$s'^2 - (0.03\bar{y})^2$	$(1/b^2 \Sigma x_i^2) \times 10^6$
90	1.074	2.358	2.860
63	1.029	2.184	3.121
58	1.045	1.116	3.024
28	0.979	1.844	3.448
48	1.079	0.721	2.838
39	1.059	0.615	2.949
62	1.054	1.107	2.972
33	1.016	2.147	3.201
70	1.058	0.653	2.953
78	1.089	6.374	2.786
—	1.045	1.590	3.024
86	1.095	1.969	2.758
47	1.058	1.004	2.950

TABLE C-2. CONSTANTS FOR 10 MR DOSIMETER REGRESSION LINES

Dosimeter No.	b	$s'^2 - (0.05\bar{y})^2$	$(1/b^2 \Sigma x_i^2) \times 10^5$
172	10.48	1.696	1.557
168	10.48	1.369	1.159
165	10.43	1.632	1.168
176	10.61	2.338	1.129
162	10.80	1.074	1.468
167	10.64	2.558	1.121
160	10.56	3.015	1.140
166	10.75	1.738	1.099
161	10.66	1.542	1.119

TABLE C-3. CONSTANTS FOR 2R DOSIMETER REGRESSION LINES IN REVERSE THROUGH THE ORIGIN

Dos. No.	b	Useful Range	$s'^2 - (0.03\bar{y})^2$	$(1/b^2 \sum x_i^2) \times 10^4$
147	56.37	$y < 29.9$	1.815	1.394
134	52.17	$y < 31.2$	1.198	2.158
137	57.10	$y < 29.5$	1.216	1.358
135	56.90	$y < 27.5$	1.451	1.814
140	55.90	$y < 27.9$	2.864	1.543
138	56.94	$y < 26.7$	2.621	1.913
151	53.53	$y < 29.6$	1.043	1.895
150	52.97	$y < 29.2$	1.126	2.147
149	52.65	$y < 30.4$	1.355	2.177
145	57.79	$y < 26.2$	1.590	1.413
144	56.74	$y < 28.8$	1.880	1.687

TABLE C-4. CONSTANTS FOR 2R DOSIMETER REGRESSION LINES IN REVERSE (NOT THROUGH THE ORIGIN)

Dos. Number	Useful Range	$\bar{x}$	a	b	$s'^2 - (0.03\bar{y})^2$	1/k	$b^2 \sum(x_i-\bar{x})^2$
147	$y > 29.9$	1.115	50.23	34.91	3.950	0.0303	7780
134	$y > 31.2$	1.099	49.04	35.35	3.705	0.0294	8319
137	$y > 29.5$	1.115	51.22	36.41	5.528	0.0303	8460
135	$y > 27.5$	1.099	49.81	36.02	4.648	0.0294	8636
140	$y > 27.9$	1.099	50.98	38.26	7.216	0.0294	9741
138	$y > 26.7$	1.099	49.98	36.74	5.489	0.0294	8983
151	$y > 29.6$	1.115	49.28	35.15	4.744	0.0303	7886
150	$y > 29.2$	1.131	50.34	36.22	4.030	0.0313	7996
149	$y > 30.4$	1.094	48.23	34.69	4.854	0.0303	7974
145	$y > 26.2$	1.099	49.91	36.55	5.581	0.0294	8893
144	$y > 28.8$	1.099	50.39	36.30	6.286	0.0294	8771

APPENDIX D

NOMENCLATURE USED IN THIS APPENDIX

$D(X,w,h,r_n \longrightarrow r_{n+1})$	=	non-skyshine component of the dose rate in a structure at a height h, from an annular source of inner radius r_n and outer radius r_{n+1}.
h	=	detector height above ground.
Q	=	the dose rate at one foot from a one curie cobalt-60 point source.
r	=	horizontal separation distance between point source and detector in the structure.
r_i	=	inner radius of finite source field (effective radius of cleared area occupied by the structure).
r_o	=	outer radius of finite source field.
r_n	=	inner radius of nth source annulus.
r_{n+1}	=	outer radius of nth source annulus.
$S(X,w,h,r_n \longrightarrow r_{n+1})$	=	skyshine component of the dose rate in a structure at a height h, from an annular source of inner radius r_n and outer radius r_{n+1}.
X	=	barrier thickness in psf.
$\bar{\alpha}_s$ (X,w,h,r)	=	skyshine structure attenuation coefficient at a height h in the structure from a ring source of radius r.
Δ	=	scale factor used for obtaining the dimensions of a scale model from the corresponding full-scale structure.
w	=	solid angle fraction subtended at a detector by a particular barrier in a structure.
μ	=	attenuation coefficient for cobalt-60 gamma radiation in air at 22°C and 760 mm of Hg.

SCALING AND FAR-FIELD CORRECTIONS TO MODEL DATA

A new and significantly better method has been developed by Kaplan, et al.,[4] to estimate the far-field contribution and to convert scale-model data to apply to the corresponding full-scale structure. The basis of this new method is the separate treatment of the skyshine and non-skyshine components of the dose rate in the model. This procedure is necessary because air density is not scaled in model experiments. Thus, the air attenuation in the model experiment is different from that in the full-scale case.

In order to use this new method, the skyshine and non-skyshine components of each of the measured total dose rates in the model must be separated. This is done by first obtaining the annular source skyshine structure attenuation factor $\bar{\alpha}_s$ (X,w) from the data of Burson and Summers[13] which is given in the form of two graphs in Kaplan's work: one for vertical barriers, and one for horizontal barriers. Therefore, it is necessary to divide a structure into its vertical and horizontal components, find the skyshine attenuation factor for each component, and then combine the factors to get $\bar{\alpha}_s$ (X,w). Having this, the finite field skyshine dose rate may be found from

$$S_m\,(X,w,h\triangle,r_i\triangle\longrightarrow r_o\triangle) = 2\pi Q k_2 \bar{\alpha}_s(X,w)\left[e^{-\mu r_i\triangle} - e^{-\mu r_o\triangle}\right]. \qquad \text{(D -1)}$$

This result is subtracted from the total measured dose rate to obtain the non-skyshine component $D_m\,(X,w,h\triangle,r_i\triangle \longrightarrow r_o\triangle)$.

The experimental data may be scaled annulus by annulus or over the entire finite source field. Since $\bar{\alpha}_s$ (X,w), k, and k_2 are nearly independent of r over the finite field, it is a good approximation to work with the results obtained from the entire field, rather than by taking each annulus separately and adding

the results. For purposes of comparison, several sets of data in this work were treated both ways. The results for the two methods were almost identical.

The expression for the far-field skyshine contribution in the full-scale case in terms of the annular shyshine dose rate from the outer annular source in the scale model is

$$S_{F.S.}(X,w,h,r_N \longrightarrow \infty) = S_m(X,w,h\Delta,r_{N-1}\Delta \longrightarrow r_N\Delta)\frac{e^{-\mu\rho_N}}{e^{-\mu\rho_{N-1}\Delta} - e^{-\mu\rho_N\Delta}} . \quad \text{(D-2)}$$

Therefore, from the skyshine dose rates in the model for the annular sources (calculated from Equation D-1), the infinite-field skyshine dose rate in the full-scale structure is

$$S_{F.S.}(X,w,h,r_1 \longrightarrow \infty) = \sum_{n=1}^{N-1} S_m(X,w,h\Delta,r_n\Delta \longrightarrow r_{n+1}\Delta)\,\frac{e^{-\mu\rho_n} - e^{-\mu\rho_{n+1}\Delta}}{e^{-\mu\rho_n\Delta} - e^{-\mu\rho_{n+1}\Delta}}.$$

$$+ S_m(X,w,h\Delta,r_{N-1}\Delta \longrightarrow r_N\Delta)\,\frac{e^{-\mu\rho_N}}{e^{-\mu\rho_{N-1}\Delta} - e^{-\mu\rho_N\Delta}} \quad \text{(D-3)}$$

The annular-source non-skyshine dose rate in the full-scale structure is

$$D_{F.S.}(X,w,h,r_1 \longrightarrow \infty) = \sum_{n=1}^{N-1} D_m(X,w,h\Delta,r_n\Delta \longrightarrow r_{n+1}\Delta)\,\frac{E_1(\mu\rho_n)-E_1(\mu\rho_{n+1})}{E_1(\mu\rho_n\Delta)-E_1(\mu\rho_{n+1}\Delta)}$$

$$+ D_m(X,w,h\Delta,r_{N-1}\Delta \longrightarrow r_N\Delta)\,\frac{E_1(\mu\rho_N)}{E_1(\mu\rho_{N-1}\Delta)-E_1(\mu\rho_N\Delta)} , \quad \text{(D-4)}$$

where the first term on the right-hand side scales the model data up to full-scale, and the second term makes the far-field correction to the data.

The method described thus far applies only to above-ground detector locations. For the instances when the detector is below ground, the above equations still hold, except that a new value of h, the detector height above ground, should be used. However, little error will be incurred when r is substituted for ρ in the scaling equations ($h=o$) if the building height above ground is small compared to a mean free path in air.

To illustrate Kaplan's method a specific example will be analyzed. The case will be considered where the detector is in the center of the basement of a one-story rectangular structure shown in the figure below. The protection factor will be found using the data from the 1:4 model of the structure.

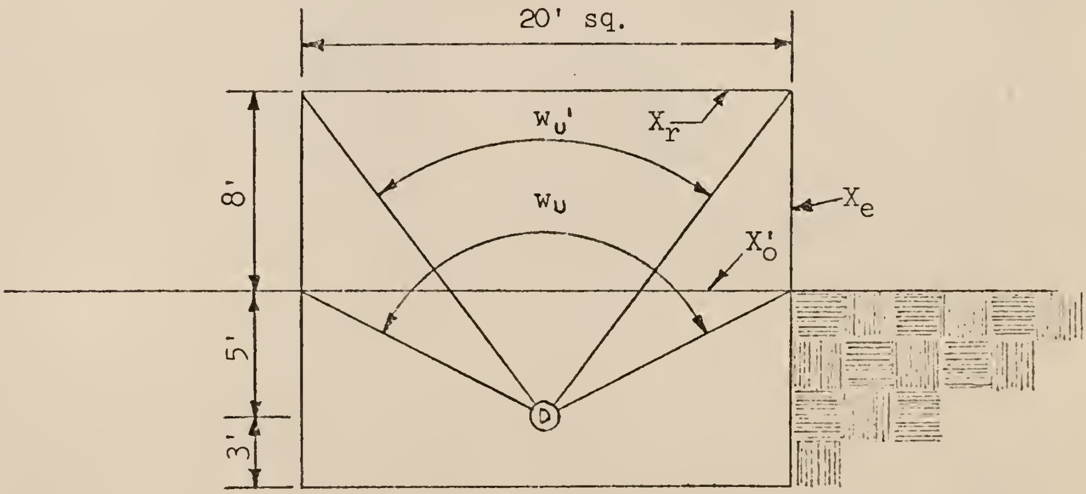


Figure 12.

Mass thicknesses: $X_e = 69$ psf

$X_f = 55$ psf

$X_r = 55$ psf

The skyshine attenuation coefficient $\bar{\alpha}_s(X,w)$ will be examined first. The ring-source skyshine attenuation coefficient through the roof is $\alpha_s^{(1)}(X_f+X_r,w_u')_H$. Next, $\alpha_s^{(3)}(X_e,w_3)_V/2$ is the ring-source skyshine attenuation coefficient for the first floor vertical wall at the center of the floor and $\alpha_s^{(2)}(X_f,w_u)_H$ is the coefficient for the first floor at the detector. Therefore, the coefficient through the floor and one wall is the product $\alpha_s^{(3)}(X_e,w_3)_V \times \alpha_s^{(2)}(X_f,w_u)_H \; / \; 2$. The total structure attenuation coefficient $\bar{\alpha}_s(X,w)$ for ring-source skyshine radiation is

$$\bar{\alpha}_s(X,w) = \alpha_s^{(1)}(X_f+X_r,w_u')_H + 4\,\frac{\alpha_s^{(3)}(X_e,w_3)_V \times \alpha_s^{(2)}(X_f,w_u)_H}{2} \qquad \text{(D-5)}$$

After substituting in the proper values and using the graphs in reference 4,

$$\bar{\alpha}_s(X,w) = \alpha_s^{(1)}(110,0.24)_H + 2\alpha_s^{(3)}(69,0.20)_V \times \alpha_s^{(2)}(55,0.60)_H \,. \qquad \text{(D-6)}$$

$$= 0.00112 + 2(0.032)(0.019)$$

$$= 0.00234$$

It is now possible to calculate the annular source dose rate in the model using Eq. D-1 and from that the dose rate in the corresponding full-scale structure from an infinite field (Eq. D-3).

$$S_m(X,w,3/4,11.42/4 \longrightarrow 160/4) = 2(3.1416)(13.94)(0.48)(0.00234) \times \left(e^{-\frac{11.42}{(478)(4)}} - e^{-\frac{160}{(478)(4)}}\right)$$

$$= 0.0073 \text{ r/hr per curie/ft}^2$$

$$S_m(X,w,3/4,108/4, \longrightarrow 160/4) = 2(3.1416)(13.94)(0.48)(0.00234) \times \left(e^{-\frac{108}{(478)(4)}} - e^{-\frac{160}{(478)(4)}}\right)$$

$$= 0.0025 \text{ r/hr per curie/ft}^2$$

Using these values in Eq. D-3 the infinite-field skyshine dose rate in the full-scale structure is

$$S_{F.S.}(X,w,3',11.42 \longrightarrow \infty) = (0.0073) \frac{e^{-\frac{11.42}{478}} - e^{-\frac{160}{478}}}{e^{-\frac{11.42}{(478)(4)}} - e^{-\frac{160}{(478)(4)}}}$$

$$+ (0.0025) \frac{e^{-\frac{160}{478}}}{e^{-\frac{108}{(478)(4)}} - e^{-\frac{160}{(478)(4)}}}$$

$$= 0.096 \text{ r/hr per curie/ft}^2$$

Next the non-skyshine dose rate in the full-scale structure will be found using Eq. D-4. The non-skyshine components in the model are determined by subtracting the skyshine dose rates calculated above from the total measured dose rate. Thus,

$$D_m(X,w,3/4,11.42/4 \longrightarrow 160/4) = (1.53 - 0.007) = 1.52 \text{ r/hr per curie/ft}^2$$

and

$$D_m(X,w,3/4,\ 108/4 \longrightarrow 160/4) = (0.0936 - 0.0025) = 0.911 \text{ r/hr per curie/ft}^2 .$$

Using this in Eq. D-4 the non-skyshine dose rate in the full-scale structure is

$$D_{F.S.}(X,w,3',11.42' \longrightarrow \infty) = (1.52) \frac{E_1\left[\frac{11.42}{478}\right] - E_1\left[\frac{160}{478}\right]}{E_1\left[\frac{11.42}{(478)(4)}\right] - E_1\left[\frac{160}{(478)(4)}\right]}$$

$$+ (0.911) \frac{E_1\left[\frac{160}{478}\right]}{E_1\left[\frac{108}{(478)(4)}\right] - E_1\left[\frac{160}{(478)(4)}\right]}$$

$$= 1.60 \text{ r/hr per curie/ft}^2 .$$

The total dose rate to the full-scale building from an infinite field is 1.70 r/hr per curie/ft^2. Therefore, the protection factor is $\frac{485}{1.7}$ or 286.

APPENDIX E

THEORETICAL PROTECTION FACTORS

The protection factor is defined as the ratio of the amount of radiation received at a point three feet above an infinite, smooth, uniformly contaminated plane to the dose received at a point in a shelter. The methods used to calculate the protection factors are described in Shelter Design and Analysis,[6] usually referred to as the "Engineering Manual". This textbook was intended to aid professional engineers and architects with the design and analysis of structures for protection against radioactive fallout.

The engineering method has proven reliable for calculations involving detectors in above-ground locations,[17] but it is deficient in the analysis of basement positions.[15] Several authors have proposed methods to adjust the basement calculations.[14,15,16] Each of these methods requires additional charts except for one developed by R. L. French. French's technique although just an extension of the engineering method is comparable in accuracy to the others.[14] The example below illustrates the fundamentals of the engineering method and includes French's extension.

Given: Structure shown in Fig. 12.

Detector located centrally in the basement.

Mass thicknesses: $X_e = 69$ psf

$X_f = 55$ psf

$X_r = 55$ psf

The contribution through the roof and vertical walls must be determined separately then combined to get the total. In the extended engineering method the ground contribution through the vertical walls is composed of two parts: That which comes from radiation not scattered in passing through the floor,

C_{g_1}; and that from radiation which does scatter in the floor, C_{g_2}. The expression for C_{g_1} is

$$C_{g_1} = B_e(X_e,H)B'_o(X_f)\left\{\left[G_a(w'_u) - G_a(w_u)\right]\left[1 - S_W(X_e)\right] + \left[G_s(w'_u) - G_s(w_u)\right] S_W(X_e)\ E(e)\right\}\left[1 - S_W(X_f)\right] \qquad (E-1)$$

where the notation is explained below. Had the non-barrier-scattered fraction $\left[1 - S_W(X_f)\right]$ been omitted from the above equation, the formulation would have represented the original engineering method expression for the entire ground contribution.

The contribution from the floor-scattered component is

$$C_{g_2} = B_e(X_e,H)B'_o(X_f)\left\{G_a(w''_u)\left[1 - S_W(X_e)\right] + G_s(w''_u)S_W(X_e)E(e)\right\} S_W(X_f)G_b(w_u)\ . \qquad (E-2)$$

The notation in the above equations is as follows:

$B_e(X_e,H)$ Barrier reduction factor for exterior wall construction as a function of the wall mass thickness and detector height.

$B'_o(X_f)$ Barrier reduction factor for ground contribution for floor immediately over the detector as a function of the mass thickness of that floor.

$G_a(w_u)$ Accounts for the skyshine radiation reaching the detector directly and also that reflected from the ceiling as a function of the upper solid angle w_u.

$G_s(w)$ Accounts for wall-scattered radiation.

$S_W(X_e)$ Fraction of emergent radiation scattered in wall barrier.

$E(e)$ Corrects for the shape of the building for wall scattered radiation; a function of eccentricity ($e = \frac{W}{L}$) of the building.

$G_b(w_u)$ The geometry factor giving the fraction of the radiation

scattered in the floor which reaches the detector. Assuming a cosine distribution for the emergent scattered radiation $G_b(w_u) = 1 - (1 - w_u)^2$.

w_u''' Solid angle fraction subtended by the walls from a point at the center of the first floor (not shown in Fig. 12).

Using the values of the above parameters found from the charts in the "Engineering Manual", the equations for C_{g_1} and C_{g_2} become

$$C_{g_1} = (0.19)(0.054)\left[(0.094 - 0.079)(0.34) + (0.45 - 0.34)(0.66)(1.414)\right](0.4)$$
$$= 0.00044 \qquad \text{(E - 3)}$$

$$C_{g_2} = (0.19)(0.054)\left[(0.088)(0.34) + (0.4)(0.66)(1.414)\right](0.6)(0.84)$$
$$= 0.00208 \qquad \text{(E - 4)}$$

The roof contribution $C_o(w_u'', X_o)$ is a function of the solid angle subtended by the roof and the mass thickness above the detector. This contribution for a decontaminated roof was found to be 0.000311.

The total reduction factor R_f is $C_o + C_{g1} + C_{g2}$. Thus,

$R_f = 0.000311 + 0.00044 + 0.00208 = 0.00284$, and $P_f = \frac{1}{R_f} = 353$.

APPENDIX F

TABLES OF DATA

In this section two complete sets of data are given: 1) The raw data as recorded in the field (Tables F-1 through F-34); and, 2) The actual doses and their standard deviations obtained from the calibration lines (Tables F-1a through F-34a). The set of data at the bottom of each page is the data at the top of the page after the necessary temperature and pressure corrections have been made, the calibration lines applied, and the data rearranged according to location in the model during exposure (See Fig. 6). For example in Run 1 of Table F-1 the reading of 123 mr from dosimeter number 58 becomes 118 $\pm$ 3.79 mr in Run 1 of Table F-1a in the NE position after application of the calibration line for dosimeter number 58.

The symbols t, T, and P in the data represent the exposure time in minutes (m), outside air temperature in ^{o}F, and pressure in inches of Hg, respectively. It should be remembered that the temperature and pressure had no bearing on the reduction of the data taken with 200 mr dosimeters although this information is supplied on the tables.

Each dosimeter is numbered according to its type as shown in the following table:

TABLE F. DOSIMETER NUMBERS ACCORDING TO TYPE

Dosimeter Number	Type	Units Read From Charger- Reader
50-100	200 mr	Milliroentgen (mr)
100-160	2 r	Microamperes (μa)
160-180	10 mr	Microamperes (μa)

The units of the data given in Tables F-1 through F-34 may be found using the above table. The units of Tables F-1a through F-34a are specified.

TABLE F-1. RAW DATA

Ground Penetration Floor Flush		AREA I (-5') A=6.69 ft^2				1:4 Model S=2.88 Curies	
Dosimeter Number	Run 1 Pos.	t=38.35 T=59 P=28.60	Run 2 Pos.	t=38.35 T=60 P=28.60	Run 3 Pos.	t=38.35 T=59 P=28.62	Run 4 Pos.	t=38.35 T=34 P=28.95

Dosimeter Number	Run 1 Pos.	Run 1 (t=38.35, T=59, P=28.60)	Run 2 Pos.	Run 2 (t=38.35, T=60, P=28.60)	Run 3 Pos.	Run 3 (t=38.35, T=59, P=28.62)	Run 4 Pos.	Run 4 (t=38.35, T=34, P=28.95)
—	N	72	C	119	W	30	C	115
58	NE	123	SW	30	C	114	W	30
70	E	100	S	49	SE	39	S	47
86	SE	40	NE	113	S	50	E	101
48	S	45	E	101	SW	28	SW	29
62	C	102	SE	39	NE	114	NE	110
90			W	33	N	67		
63			N	59	E	95	SE	41
165			NW	33				
162	NW	33						
172					NW	33		
176							NW	33

TABLE F-1a. DATA (MR) AFTER USE OF CALIBRATION LINES

Position	Run 1 t=38.35m	Run 2 t=38.35m	Run 3 t=38.35	Run 4 t=38.35
S	41.7 ± 1.50	46.3 ± 1.61	45.7 ± 1.90	44.4 ± 1.56
E	94.5 ± 3.01	93.6 ± 2.99	92.3 ± 3.20	92.3 ± 3.12
N	68.9 ± 2.44	57.3 ± 2.28	62.3 ± 2.39	
W		30.7 ± 1.72	28.7 ± 1.50	28.7 ± 1.34
SE	36.5 ± 1.71	37.0 ± 1.51	36.9 ± 1.36	39.9 ± 1.89
SW		28.7 ± 1.34	26.0 ± 1.12	26.9 ± 1.14
NE	118 ± 3.79	103 ± 3.44	108 ± 3.49	104 ± 3.38
NW	3.12 ± 0.187	3.24 ± 0.206	3.21 ± 0.206	2.99 ± 0.211
C	96.7 ± 3.15	114 ± 3.74	109 ± 3.53	110 ± 3.62

TABLE F-2. RAW DATA

Floor Flush
First Floor

AREA I (-5')
$A=6.69\ ft^2$

1:4 Model
S=2.88 Curies

Dosimeter Number	Run 1 Pos.	Run 1 t=44.75m T=70 P=28.63	Run 2 Pos.	Run 2 t=38.35m T=71 P=28.63	Run 3 Pos.	Run 3 t=38.35m T=71 P=28.58	Run 4 Pos.	Run 4 t=38.35m T=72 P=28.57
48	S	200	SE	156	SW	121	W	150
—	SE	178	W	147	S	180	NW	78
90			NW	79	NW	77	SW	120
63	SW	130	SW	113	SE	146	S	173
33	W	162						
39	NW	87	S	180	W	148	SE	152
134	NE	73.5	E	23	C	21	E	17
147	N	46.5						
135			N	41	NE	64	C	25
151			NE	63	E	22.5	N	41
140			C	17.5	N	44	E	63.5

TABLE F-2a. DATA (MR) AFTER USE OF CALIBRATION LINES

Position	Run 1 t=44.75m	Run 2 t=38.35m	Run 3 t=38.35m	Run 4 t=38.35m
S		170 ± 5.45	172 ± 5.62	168 ± 5.54
E		460 ± 26.9	440 ± 24.6	341 ± 24.4
N	1060 ± 72.3	904 ± 71.5	969 ± 80.9	935 ± 74.0
W	159 ± 5.25	141 ± 4.58	140 ± 4.44	139 ± 4.42
SE	170 ± 5.55	145 ± 4.60	142 ± 4.69	144 ± 4.56
SW	126 ± 4.20	110 ± 3.70	112 ± 3.56	111 ± 3.75
NE	1880 ± 90.7	1580 ± 87.1	1570 ± 85.2	1510 ± 90.7
NW	822 ± 2.63	73.5 ± 2.68	71.7 ± 2.63	74.6 ± 2.59
C		326 ± 32.6	420 ± 25.9	460 ± 26.8

TABLE F=3. RAW DATA

Floor Flush Basement	AREA I (-5') $A=6.69\ ft^2$	1:4 Model S=2.88 Curies

Dosimeter Number	Pos.	Run 1 t=44.75 T=70 P=28.63	Pos.	Run 2 t=38.35 T=71 P=28.63	Pos.	Run 3 t=38.35 T=71 P=28.58	Pos.	Run 4 t=38.35 T=72 P=28.57
47	C	187	SW	45	E	141	NE	120
62	E	170	N	79	S	84	SW	47
86	NE	149	S	82	W	49	E	138
172	NW	74					NW	60
176					NW	62.5		
165			NW	60				
70	N	93	SE	75	C	153	S	78
33			E	132	SE	77	C	141
58			W	46	NE	125	N	74
28			C	140	N	73	W	40
78			NE	142	SW	60	SE	80

TABLE F-3a. DATA (MR) AFTER USE OF CALIBRATION LINES

Position	Run 1 t=44.75m	Run 2 t=38.35m	Run 3 t=38.35m	Run 4 t=38.35m
S		74.9 ± 2.64	79.7 ± 2.64	73.7 ± 2.38
E	161 ± 5.20	130 ± 4.31	133 ± 4.27	126 ± 4.14
N	87.9 ± 2.81	74.9 ± 2.51	74.6 ± 2.68	70.8 ± 2.40
W		44.0 ± 1.68	44.8 ± 1.88	40.9 ± 1.87
SE		70.9 ± 2.30	75.8 ± 2.75	73.5 ± 3.26
SW		42.5 ± 1.61	55.1 ± 2.89	44.6 ± 1.69
NE	136 ± 4.45	130 ± 4.72	120 ± 3.85	113 ± 3.64
NW	7.35 ± 0.409	6.00 ± 0.335	6.16 ± 0.351	6.00 ± 0.337
C	177 ± 5.71	143 ± 4.71	145 ± 4.60	139 ± 4.59

TABLE F-4. RAW DATA

Floor Flush First Floor		AREA II (5'-27') A=1105 ft^2				1:4 Model S=76.99 Curies	
Dosimeter Number	Run 1 Pos.	t=23.28m T=42 P=28.92	Run 2 Pos.	t=52.42m T=45 P=28.85	Run 3 Pos.	t=51.40m T=53 P=28.79	Run 4 Pos.	t=40.97m T=55 P=28.75
134	N	20	NW	26	W	27	E	37
147	NE	33.5	SW	27.5	N	36.5	SE	50
137	E	24.5	C	38.5	NE	60	S	33
149	SE	32	NE	60	SE	60	C	34
138	S	19	E	43	SW	27.5	N	30.5
135	SW	13	N	37	NW	29	NW	24.5
144	W	14.5	SE	60	S	38	NE	52.5
151	NW	13	W	25.5	C	37	W	23.5
140	C	21	S	37	E	46.5	SW	25

TABLE F-4a. DATA (R) AFTER USE OF CALIBRATION LINES

Position	Run 1 t=23.28m	Run 2 t=52.42m	Run 3 t=51.40m	Run 4 t=40.97m
S	0.326 $\pm$ 0.031	0.720 $\pm$ 0.078	0.761 $\pm$ 0.078	0.621 $\pm$ 0.073
E	0.419 $\pm$ 0.024	0.891 $\pm$ 0.075	0.986 $\pm$ 0.081	0.767 $\pm$ 0.065
N	0.375 $\pm$ 0.025	0.728 $\pm$ 0.069	0.724 $\pm$ 0.067	0.576 $\pm$ 0.072
W	0.250 $\pm$ 0.026	0.469 $\pm$ 0.025	0.519 $\pm$ 0.028	0.443 $\pm$ 0.025
SE	0.605 $\pm$ 0.072	1.34 $\pm$ 0.087	1.44 $\pm$ 0.085	1.12 $\pm$ 0.073
SW	0.224 $\pm$ 0.022	0.481 $\pm$ 0.030	0.489 $\pm$ 0.071	0.450 $\pm$ 0.035
NE	0.613 $\pm$ 0.066	1.41 $\pm$ 0.084	1.36 $\pm$ 0.084	1.17 $\pm$ 0.084
NW	0.238 $\pm$ 0.021	0.491 $\pm$ 0.028	0.524 $\pm$ 0.068	0.434 $\pm$ 0.026
C	0.367 $\pm$ 0.033	0.750 $\pm$ 0.074	0.768 $\pm$ 0.072	0.692 $\pm$ 0.073

TABLE F-5. RAW DATA

Floor Flush Basement	AREA II (5' - 27') $A=1105\ ft^2$	1:4 Model $S=76.17$ Curies

Dosimeter Number	Run 1 Pos.	Run 1 t=18.22m T=50 P=29.12	Run 2 Pos.	Run 2 t=20.25m T=59 P=29.14	Run 3 Pos.	Run 3 t=35.58m T=52 P=29.01	Run 4 Pos.	Run 4 t=37.97m T=55 P=28.99	Run 5 Pos.	Run 5 t=17.23m T=69 P=28.53
160									NE	15
161	W	21.5	NE	20	W	42	E	45.5	S	20
173	NW	13.5	SE	17						
165	C	39	SW	13	SE	30.5	NE	35	N	18.5
172	NE	17.5	N	22.5	NE	33	C	86	SE	14
176	E	21.5	E	23.5	C	79	SE	33.5	W	18
168	S	21	NW	13			N	44.5	SW	12
167	SW	12	C	43	NW	23	S	48.5	E	19
166					SW	24	NW	24.5	NW	11
162					N	42	W	45	C	34

TABLE F-5a. DATA (IN MR) AFTER USE OF CALIBRATION LINES

Position	Run 1 t=18.22m	Run 2 t=20.25m	Run 3 t=35.58m	Run 4 t=37.97m	Run 5 t=17.23m
S	1.98 ± 0.151			4.56 ± 0.279	1.96 ± 0.155
E	2.00 ± 0.177	2.22 ± 0.185		4.27 ± 0.249	1.86 ± 0.179
N		2.15 ± 0.166	3.86 ± 0.220	4.25 ± 0.245	1.85 ± 0.156
W	1.99 ± 0.156		3.91 ± 0.232	4.17 ± 0.234	1.77 ± 0.170
SE		1.62 ± 0.150	2.90 ± 0.193	3.16 ± 0.217	1.39 ± 0.144
SW	1.11 ± 0.162	1.25 ± 0.139	2.22 ± 0.167		1.19 ± 0.129
NE	1.64 ± 0.151	1.88 ± 0.151	3.13 ± 0.203	3.36 ± 0.212	1.48 ± 0.183
NW	1.27 ± 0.140	1.24 ± 0.130	2.15 ± 0.187	2.28 ± 0.170	1.068 ± 0.135
C	3.69 ± 0.226	4.05 ± 0.257	7.39 ± 0.415	8.19 ± 0.467	3.29 ± 0.193

TABLE F-6. RAW DATA

Floor Flush First Floor		AREA III (27'-40') A=1368 ft^2		1:4 Model S=76.17 Curies		
Dosimeter Number	Pos.	Run 1 t=44.03m T=70 P=28.47	Pos.	Run 2 t=44.27m T=67 P=28.47	Pos.	Run 3 t=44.15m T=65 P=28.55
—	NE	170	NW	101	C	130
90	N	119	SE	182	W	103
58	E	129	W	100	NE	165
63	NW	99.5	SW	100.5	E	127
48	W	105	C	133	SW	108
62	SW	101	NE	170	S	116
33	S	114	N	109	NW	98
86	SE	181	E	137	N	120
70	C	125	S	117	SE	172

TABLE F-6a. DATA (MR) AFTER USE OF CALIBRATION LINES

Position	Run 1 t=44.03m	Run 2 t=44.27m	Run 3 t=44.15m
S	112 $\pm$ 3.78	111 $\pm$ 3.51	110 $\pm$ 3.55
E	123 $\pm$ 3.97	125 $\pm$ 4.11	123 $\pm$ 4.11
N	111 $\pm$ 3.73	107 $\pm$ 3.63	110 $\pm$ 3.64
W	97.3 $\pm$ 3.10	95.7 $\pm$ 3.12	95.8 $\pm$ 3.29
SE	165 $\pm$ 5.40	169 $\pm$ 5.58	163 $\pm$ 5.20
SW	95.8 $\pm$ 3.11	97.7 $\pm$ 3.35	100 $\pm$ 3.19
NE	163 $\pm$ 5.29	161 $\pm$ 5.20	158 $\pm$ 5.09
NW	96.7 $\pm$ 3.32	96.6 $\pm$ 3.22	96.5 $\pm$ 3.32
C	118 $\pm$ 3.75	123 $\pm$ 3.91	124 $\pm$ 4.06

TABLE F-7. RAW DATA

Floor Flush Basement		AREA III (27'-40') A=1368 ft^2				1:4 Model S=76.17 Curies	
Dosimeter Number	Run 1		Run 2		Run 3		Run 4
	Pos.	t=54.70m T=71 P=28.52	Pos.	t=88.03m T=70 P=28.47	Pos.	t=67.67m T=67 P=28.47	Pos.	t=65.07m T=65 P=28.55
165	W	14.5	N	20	C	28	SE	9
160	SW	8.5	NE	10	NW	10.2	E	14
162	S	13	SW	13.5	NE	8.5	N	19
161			E	17	S	16.5	C	27.5
168	E	10.5	C	37	SE	9	NW	10.5
176	NE	7	SE	11.5	N	15	W	19
167	N	13	NW	13	SW	11.5	S	16.5
166	NW	8.5	S	21	W	18	NE	8
172	C	27	W	23	E	14.5	SW	10.3

TABLE F-7a. DATA (MR) AFTER USE OF CALIBRATION LINES

Position	Run 1 t=54.70m	Run 2 t=88.03m	Run 3 t=67.67m	Run 4 t=65.07m
S	1.26 $\pm$ 0.116	2.05 $\pm$ 0.162	1.61 $\pm$ 0.144	1.60 $\pm$ 0.172
E	1.05 $\pm$ 0.124	1.67 $\pm$ 0.145	1.44 $\pm$ 0.145	1.37 $\pm$ 0.180
N	1.28 $\pm$ 0.165	2.01 $\pm$ 0.160	1.47 $\pm$ 0.164	1.82 $\pm$ 0.134
W	1.46 $\pm$ 0.144	2.30 $\pm$ 0.172	1.74 $\pm$ 0.152	1.85 $\pm$ 0.174
SE		1.14 $\pm$ 0.156	0.896 $\pm$ 0.122	0.893 $\pm$ 0.132
SW	0.844 $\pm$ 0.172	1.31 $\pm$ 0.118	1.13 $\pm$ 0.162	1.02 $\pm$ 0.136
NE	0.692 $\pm$ 0.150	0.992 $\pm$ 0.174	0.820 $\pm$ 0.106	0.770 $\pm$ 0.130
NW	0.829 $\pm$ 0.131	1.28 $\pm$ 0.165	1.01 $\pm$ 0.173	1.04 $\pm$ 0.124
C	2.70 $\pm$ 0.186	3.70 $\pm$ 0.220	2.80 $\pm$ 0.189	2.67 $\pm$ 0.179

TABLE F-8. RAW DATA

Floor Flush	AREA IV (40'-60')	1:4 Model
First Floor	A=3142 ft^2	S=76.99 Curies

Dosimeter Number	Run 1 Pos.	t=23.78m T=71 P=28.81	Run 2 Pos.	t=50.02m T=74 P=28.79	Run 3 Pos.	t=55.17m T=77 P=28.84	Run 4 Pos.	t=44.17m T=78 P=28.83
—	NE	40	E	60	W	57	N	48
62	E	27	SE	79	S	59.5	C	53
58	SE	39	NE	77	N	58.5	E	51
70	S	25	SW	49	C	63	NW	42
86	SW	25	N	53	NW	55	W	44
48	W	24	C	60	NE	88.5	SW	47
47	NW	26	W	52	E	67	SE	72
33	N	24	NW	48	SW	53	E	48.5
63	C	28	S	52	SE	84	NE	68

TABLE F-8a. DATA (MR) AFTER USE OF CALIBRATION LINES

Position	Run 1 t=23.78m	Run 2 t=50.02m	Run 3 t=55.17m	Run 4 t=44.17m
S	23.6 ± 1.05	50.5 ± 2.12	56.4 ± 1.99	47.7 ± 2.06
E	25.6 ± 1.27	57.4 ± 2.14	63.3 ± 2.16	48.8 ± 1.80
N	23.6 ± 1.62	48.4 ± 1.96	56.0 ± 1.99	45.9 ± 1.86
W	22.2 ± 1.04	49.1 ± 1.78	54.5 ± 2.06	40.2 ± 1.78
SE	37.3 ± 1.53	74.9 ± 2.51	81.7 ± 2.89	68.0 ± 2.29
SW	22.8 ± 1.47	46.3 ± 1.61	52.2 ± 2.16	43.6 ± 1.55
NE	38.3 ± 1.67	73.7 ± 2.48	82.0 ± 2.64	66.1 ± 2.49
NW	24.6 ± 1.21	47.3 ± 2.05	50.3 ± 2.01	39.7 ± 1.43
C	27.2 ± 1.67	55.6 ± 1.87	59.6 ± 1.97	50.3 ± 1.83

TABLE F-9. RAW DATA

Ground Penetration Floor Elevated	AREA I (-5') A=6.69 ft^2	1:4 Model S=2.88 Curies

Dosimeter Number	Run 1 Pos.	t=44.75m T=34 P=28.96	Run 2 Pos.	t=44.75m T=35 P=28.96	Run 3 Pos.	t=44.75m T=33 P=28.96	Run 4 Pos.	t=44.75m T=32 P=29.15	Run 5 Pos.	t=44.75m T=33 P=29.13
—	SW	20	S	37			E	110	W	27
86	S	36	W	30			S	39		
70	W	29			E	111	W	29	S	30
48	SE	30	E	112	W	30	SE	32	SW	19
176	NW	40								
165			NW	38.5					NW	37
90					SE	33				
63					SW	22				
62			SW	20					SE	29
58					S	31	SW	23	E	100
172							NW	41.5		

TABLE F-9a. DATA (MR) AFTER USE OF CALIBRATION LINES

Position	Run 1 t=44.75m	Run 2 t=44.75m	Run 3 t=44.75m	Run 4 t=44.75m	Run 5 t=44.75m
S	32.9 ± 1.64	35.4 ± 1.63	29.7 ± 1.36	35.6 ± 1.69	28.4 ± 1.16
E		103 ± 3.30	104 ± 3.33	105 ± 3.48	96.7 ± 3.12
N					
W	27.4 ± 1.14	27.4 ± 1.54	27.8 ± 1.16	27.4 ± 1.14	25.8 ± 1.45
SE	27.8 ± 1.16		30.7 ± 1.72	29.7 ± 1.20	27.5 ± 1.31
SW	19.1 ± 1.35	18.9 ± 1.16	21.3 ± 1.59	22.0 ± 1.22	17.6 ± 0.957
NE					
NW	3.62 ± 0.235	3.55 ± 0.219		3.76 ± 0.230	3.38 ± 0.212
C					

TABLE F-10. RAW DATA

Ground Penetration Floor Elevated			AREA I (-5') A=6.69 ft^2				1:4 Model S=2.88 Curies	
Dosimeter Number	Run 1 Pos.	t=16.0m T=51 P=28.60	Run 2 Pos.	t=16.0m T=51 P=28.63	Run 3 Pos.	t=16.0m T=50 P=28.65	Run 4 Pos.	t=16.0m T=50 P=28.67
48	NE	178	C	45	N	105	N	99
—	C	48	N	90	NE	167	NE	160
70	N	94	NE	165	C	41	C	47

TABLE F-10a. DATA (MR) AFTER USE OF CALIBRATION LINES

Position	Run 1 t=16.0m	Run 2 t=16.0m	Run 3 t=16.0m	Run 4 t=16.0m
N	88.9 ± 2.84	86.1 ± 2.92	97.3 ± 3.10	91.8 ± 2.93
NE	165 ± 5.29	156 ± 4.98	160 ± 5.20	153 ± 4.98
C	45.9 ± 1.86	41.7 ± 1.50	38.8 ± 1.41	44.4 ± 1.56

TABLE F-11. RAW DATA

Floor Elevated First Floor		AREA I (-5') $A=6.69\ ft^2$				1:4 Model S=2.88 Curies	
Dosimeter Number	Run 1 Pos.	t=44.75m T=66 P=28.61	Run 2 Pos.	t=44.75m T=70 P=28.61	Run 3 Pos.	t=44.75m T=64 P=28.69	Run 4 Pos.	t=44.75m T=68 P=28.69
63	SW	27	SW	29	S	37	NW	66
33	S	38	SE	33	NW	63	E	113
90	NW	70	W	60	E	112	C	123
39	C	127	S	40	C	127	SE	33
—	W	60	NW	73	SE	35	S	39.5
86	E	114	C	130	SW	29	W	59
145	N	29	NE	37	N	26.5	NE	37
28	SE	30			W	51	SW	26
134	NE	41	N	29	NE	35	N	27.5
58			E	121				

TABLE F-11a. DATA (MR) AFTER USE OF CALIBRATION LINES

Position	Run 1 t=44.75m	Run 2 t=44.75m	Run 3 t=44.75m	Run 4 t=44.75m
S	37.4 ± 1.85	37.8 ± 1.37	36.0 ± 1.82	37.8 ± 1.68
E	104 ± 3.47	116 ± 3.73	104 ± 3.53	111 ± 3.75
N	554 ± 72.4	579 ± 30.2	479 ± 72.0	546 ± 29.2
W	57.4 ± 2.14	55.8 ± 2.23	52.1 ± 2.12	53.9 ± 2.09
SE	30.6 ± 1.68	32.5 ± 1.76	33.5 ± 1.59	31.2 ± 1.21
SW	26.2 ± 1.66	28.2 ± 1.69	26.5 ± 1.53	26.6 ± 1.62
NE	912 ± 67.0	789 ± 74.2	729 ± 64.6	782 ± 73.9
NW	65.1 ± 2.46	69.8 ± 2.46	62.0 ± 2.39	64.2 ± 2.44
C	120 ± 3.80	119 ± 3.92	120 ± 3.80	114 ± 3.84

TABLE F-12. RAW DATA

Floor Elevated Basement	AREA I (-5') A=6.69 ft^2	1:4 Model S=2.88 Curies

Dosimeter Number	Run 1 Pos.	Run 1 t=44.75m T=66 P=28.61	Run 2 Pos.	Run 2 t=44.75m T=70 P=28.61	Run 3 Pos.	Run 3 t=44.75m T=64 P=28.69	Run 4 Pos.	Run 4 t=44.75m T=68 P=28.69
58	SW	73			SE	107	W	102
48			NW	13	W	109	SE	115
147	C	21	N	18	NE	27	E	18
151	N	18.5	NE	27	C	16	NE	27
135	NE	31	E	18.5	N	16.5	C	19
62	S	118	SE	109	NW	10	SW	77
47	W	106	SW	79	S	128	NW	10
70	NW	13	W	100	SW	77	S	120
78	SE	110	S	127				
137			C	19	E	14	N	19

TABLE F-12a. DATA (MR) AFTER USE OF CALIBRATION LINES

Position	Run 1 t=44.75m	Run 2 t=44.75m	Run 3 t=44.75m	Run 4 t=44.75m
S	112 ± 3.61	117 ± 4.33	121 ± 3.88	113 ± 3.60
E		339 ± 24.3	252 ± 21.3	331 ± 26.8
N	358 ± 22.8	333 ± 26.8	298 ± 23.6	345 ± 22.7
W	100 ± 3.24	94.5 ± 3.01	101 ± 3.22	97.6 ± 3.18
SE	101 ± 3.92	103 ± 3.35	102 ± 3.32	106 ± 3.39
SW	69.8 ± 2.37	74.7 ± 2.48	72.8 ± 2.36	73.0 ± 2.45
NE	607 ± 68.3	526 ± 26.8	493 ± 29.8	522 ± 26.7
NW	12.3 ± 0.857	12.0 ± 0.875	9.49 ± 1.05	9.46 ± 0.998
C	386 ± 27.7	347 ± 22.7	307 ± 21.9	346 ± 24.4

TABLE F-13. RAW DATA

Floor Elevated First Floor		AREA II (5'-27') A=1105 ft^2				1:4 Model S=76.17 Curies	
	Run 1		Run 2		Run 3		Run 4
Dosimeter Number	Pos.	t=18.43m T=48 P=28.99	Pos.	t=36.97m T=49 P=28.98	Pos.	t=40.47m T=50 P=28.97	Pos.	t=34.68m T=52 P=28.69

Dosimeter Number	Run 1 Pos.	Run 1 (t=18.43m, T=48, P=28.99)	Run 2 Pos.	Run 2 (t=36.97m, T=49, P=28.98)	Run 3 Pos.	Run 3 (t=40.47m, T=50, P=28.97)	Run 4 Pos.	Run 4 (t=34.68m, T=52, P=28.69)
137	NE	27.5	S	27	NW	21.5	E	34
151	E	21	SW	19	N	31	S	29
144	SE	32.5	E	30.5	W	25.5	NW	21
135	S	20	NE	44	C	35	N	26
140			NW	25	E	39.5	C	26.5
138			C	30.5	SW	22	NE	44
147	N	20.5	SE	45.5	S	31	W	20
145	NW	17	N	29	SE	47.5	SW	21
134	C	20	W	18	NE	49.5	SE	43.5

TABLE F-13a. DATA (R) AFTER USE OF CALIBRATION LINES

Position	Run 1 t=18.43m	Run 2 t=36.97m	Run 3 t=40.47m	Run 4 t=34.68m
S	0.347 $\pm$ 0.024	0.468 $\pm$ 0.025	0.554 $\pm$ 0.066	0.545 $\pm$ 0.027
E	0.387 $\pm$ 0.023	0.541 $\pm$ 0.077	0.790 $\pm$ 0.079	0.646 $\pm$ 0.073
N	0.359 $\pm$ 0.027	0.518 $\pm$ 0.072	0.587 $\pm$ 0.070	0.459 $\pm$ 0.027
W		0.341 $\pm$ 0.024	0.445 $\pm$ 0.029	0.357 $\pm$ 0.027
SE	0.594 $\pm$ 0.077	0.964 $\pm$ 0.071	1.02 $\pm$ 0.077	0.948 $\pm$ 0.068
SW		0.351 $\pm$ 0.023	0.383 $\pm$ 0.032	0.365 $\pm$ 0.025
NE	0.475 $\pm$ 0.025	0.924 $\pm$ 0.072	1.10 $\pm$ 0.070	0.941 $\pm$ 0.075
NW	0.290 $\pm$ 0.024	0.442 $\pm$ 0.035	0.373 $\pm$ 0.023	0.371 $\pm$ 0.028
C	0.378 $\pm$ 0.025	0.559 $\pm$ 0.072	0.679 $\pm$ 0.069	0.477 $\pm$ 0.035

TABLE F-14. RAW DATA

Floor Elevated Basement			AREA II (5'-27') A=1105 ft^2		1:4 Model S=76.17 Curies	
Dosimeter Number	Run 1		Run 2		Run 3	
	Pos.	t=36.97 T=48 P=28.99	Pos.	t=40.47 T=49 P=28.98	Pos.	t=34.68 T=50 P=28.97
70	NW	24	S	40	W	40
86	SW	28	C	77	N	31
33	S	30	NE	13	NW	23
90	W	45	SE	19	S	34
63	N	30	SW	29	C	60
62	NE	16	W	45	SE	13
—	E	28	N	38	SW	25
48	SE	15	E	30	NE	12
58	C	65	NW	30	E	27

TABLE F-14a. DATA (MR) AFTER USE OF CALIBRATION LINES

Position	Run 1 t=36.97	Run 2 t=40.47	Run 3 t=34.68
S	29.5 ± 1.71	37.8 ± 1.39	31.6 ± 1.74
E	26.8 ± 1.47	27.8 ± 1.16	25.8 ± 1.29
N	29.2 ± 1.70	36.4 ± 1.65	28.3 ± 1.56
W	41.9 ± 1.93	42.7 ± 1.64	37.8 ± 1.39
SE	13.9 ± 0.900	17.7 ± 1.54	12.3 ± 1.08
SW	25.6 ± 1.51	28.2 ± 1.69	23.9 ± 1.42
NE	15.2 ± 1.11	12.8 ± 1.51	11.1 ± 0.863
NW	22.7 ± 1.03	28.7 ± 1.34	22.6 ± 1.61
C	62.2 ± 2.16	70.4 ± 2.51	58.3 ± 2.30

TABLE F-15. RAW DATA

Floor Elevated First Floor	AREA III (27' - 40') A=1368 ft^2	1:4 Model S=76.17 Curies

Dosimeter Number	Pos.	Run 1 t=19.73m T=52 P=28.70	Pos.	Run 2 t=12.90m T=31 P=28.97	Pos.	Run 3 t=28.25m T=32 P=28.97	Pos.	Run 4 t=19.05m T=22 P=28.81
63	NE	80	N	36	W	65	NW	40
28	E	59						
90	SE	87	S	40	E	91	N	54
—	S	56	E	40	SE	121	W	45
86	SW	51	NE	56	N	80	E	60
48	W	50	SW	34	C	90	SE	81
33	NW	46	W	32	NE	112	SW	40
58	N	55	C	41	S	79	NE	79
62	C	60	NW	31	SW	69	S	52
70			SE	54	NW	69	C	57

TABLE F-15a. DATA (MR) AFTER USE OF CALIBRATION LINES

Position	Run 1 t=19.73m	Run 2 t=12.90m	Run 3 t=28.25m	Run 4 t=19.05m
S	53.6 ± 2.04	37.2 ± 1.84	75.6 ± 2.53	49.3 ± 1.81
E	60.3 ± 2.32	38.3 ± 1.69	84.7 ± 2.98	54.8 ± 2.12
N	52.6 ± 1.90	35.0 ± 1.80	73.1 ± 2.59	50.2 ± 2.11
W	46.3 ± 1.62	31.5 ± 1.74	63.2 ± 2.42	43.1 ± 1.79
SE	80.9 ± 2.88	51.1 ± 1.74	116 ± 3.79	75.1 ± 2.43
SW	46.6 ± 1.92	31.5 ± 1.24	65.4 ± 2.24	39.4 ± 1.89
NE	77.8 ± 2.79	51.2 ± 2.03	110 ± 3.72	75.6 ± 2.53
NW	45.3 ± 2.01	29.4 ± 1.35	65.2 ± 2.14	38.9 ± 1.87
C	56.9 ± 2.01	39.2 ± 1.57	83.4 ± 2.68	53.9 ± 1.81

TABLE F-16. RAW DATA

Floor Elevated Basement	AREA III (27' - 40') $A=1368\ ft^2$	1:4 Model S=76.17 Curies

Dosimeter Number	Pos.	Run 1 t=19.73m T=52 P=28.70	Pos.	Run 2 t=12.90m T=31 P=28.97	Pos.	Run 3 t=28.25m T=32 P=28.97	Pos.	Run 4 t=19.05m T=22 P=28.91
166	N	34	SE	8.6	E	31	NE	13
176	NE	12.5	W	29.5	C	89	N	34.5
162	NW	27	NE	9.5	W	65	SE	14
161	E	21.5	NW	18	NW	39.5	SW	25
172	W	44			SW	35.5	C	62
165	SE	13	SW	16.5	N	49	S	32
160	S	31.5	C	43	NE	19	E	21
168	SW	24.5	E	15	S	46	NW	27
167			N	23.5	SE	20	W	45

TABLE F-16a. DATA (MR) AFTER USE OF CALIBRATION LINES

Position	Run 1 t=19.73m	Run 2 t=12.90m	Run 3 t=28.25m	Run 4 t=19.05
S	3.00 ± 0.226		4.20 ± 0.242	2.88 ± 0.192
E	2.03 ± 0.157	1.37 ± 0.132	2.76 ± 0.187	1.87 ± 0.191
N	3.17 ± 0.204	2.11 ± 0.186	4.49 ± 0.262	3.05 ± 0.213
W	4.21 ± 0.251	2.65 ± 0.199	5.75 ± 0.314	3.97 ± 0.254
SE	1.25 ± 0.137	0.763 ± 0.13	1.80 ± 0.177	1.22 ± 0.115
SW	2.35 ± 0.164	1.51 ± 0.146	3.24 ± 0.207	2.20 ± 0.162
NE	1.18 ± 0.158	0.839 ± 0.106	1.72 ± 0.188	1.13 ± 0.136
NW	2.51 ± 0.160	1.61 ± 0.144	3.54 ± 0.216	2.42 ± 0.166
C		3.88 ± 0.259	8.02 ± 0.356	5.55 ± 0.314

TABLE F-17. RAW DATA

Floor Elevated First Floor	AREA IV (40'-60') A=3142 ft^2	1:4 Model S=76.17 Curies

Dosimeter Number	Run 1 Pos.	t=67.88m T=26 P=29.05	Run 2 Pos.	t=58.13m T=29 P=29.05	Run 3 Pos.	t=59.43m T=31 P=28.98
62	N	75	NW	59	W	58
90	NE	120	C	75	SE	103
58	E	82	S	67	NE	98
33	SE	111	N	61	S	64
86	S	78	SW	61	NW	61
63	SW	68	E	69	N	65
—	W	70	NE	100	SW	61
48	NW	70	SE	100	E	75
70	C	82	W	59	C	72

TABLE F-17a. DATA (MR) AFTER USE OF CALIBRATION LINES

Position	Run 1 t=67.88m	Run 2 t=58.13m	Run 3 t=59.43m
S	71.3 ± 2.54	64.1 ± 2.21	63.0 ± 2.42
E	78.5 ± 2.61	67.1 ± 2.52	69.5 ± 2.27
N	71.1 ± 2.40	60.0 ± 2.34	63.2 ± 2.42
W	67.0 ± 2.38	55.8 ± 1.87	55.0 ± 1.96
SE	109 ± 3.69	92.7 ± 2.96	95.8 ± 3.29
SW	66.1 ± 2.49	55.7 ± 2.14	58.4 ± 2.16
NE	112 ± 3.75	95.7 ± 0.192	93.8 ± 3.06
NW	64.9 ± 2.14	56.0 ± 1.98	55.7 ± 2.14
C	77.5 ± 2.50	69.8 ± 2.58	68.1 ± 2.22

TABLE F-18. RAW DATA

Floor Elevated Basement		AREA IV (40'-60') A=3142 ft^2			1:4 Model S=76.17 Curies	
Dosimeter Number	Pos.	Run 1 t=67.88m T=26 P=29.05	Pos.	Run 2 t=58.13m T=29 P=29.05	Pos.	Run 3 t=59.43m T=31 P=28.98
162	SE	19	NE	16.5	C	76
172	C	90	E	25.5	NE	16
166	E	29	N	40	SW	30
167	NE	19	SW	30.5	E	26
165	N	45	C	71.5	NW	31.5
168	NW	37	SE	15.5	W	51.5
161	W	61	S	37	SE	16
176	SW	35	W	53	S	39
160	S	45	NW	33	N	40

TABLE F-18a. DATA (MR) AFTER USE OF CALIBRATION LINES

Position	Run 1 t=67.88m	Run 2 t=58.13m	Run 3 t=59.43m
S	4.01 $\pm$ 0.265	3.29 $\pm$ 0.205	3.51 $\pm$ 0.231
E	2.54 $\pm$ 0.179	2.30 $\pm$ 0.172	2.33 $\pm$ 0.192
N	4.06 $\pm$ 0.242	3.52 $\pm$ 0.218	3.61 $\pm$ 0.249
W	5.39 $\pm$ 0.301	4.73 $\pm$ 0.284	4.69 $\pm$ 0.266
SE	1.66 $\pm$ 0.128	1.40 $\pm$ 0.133	1.43 $\pm$ 0.138
SW	3.11 $\pm$ 0.215	2.71 $\pm$ 0.205	2.66 $\pm$ 0.184
NE	1.68 $\pm$ 0.174	1.45 $\pm$ 0.122	1.45 $\pm$ 0.146
NW	3.33 $\pm$ 0.204	2.96 $\pm$ 0.225	2.88 $\pm$ 0.192
C	8.08 $\pm$ 0.450	6.49 $\pm$ 0.360	6.71 $\pm$ 0.365

TABLE F-19. RAW DATA

Ground Penetration — Floor Flush — AREA I (-20") — $A=0.69\ ft^2$ — 1:12 Model — S=0.227 Curies

Dosimeter Number	Run 1 Pos.	t=42.22m T-36 P=29.04	Run 2 Pos.	t=42.22m T-37 P=29.03	Run 3 Pos.	t=42.22m T-32 P=28.99	Run 4 Pos.	t=42.22m T-35 P=28.93
—	NE	68	N	120	NE	70	N	118
48	N	129	NW	64	SW	69.5	NE	65
58	NW	68	W	84	NW	63	W	80
39	W	79						
70	SW	72			W	82	SW	65
90			SW	70.5				
63			NE	65	N	111	NW	54
134	SE	40.5	SE	37	SE	36.5	C	15
151	E	30	C	15	S	13.5	SE	31.5
140			E	39	E	27.5	S	16.5
135			S	16	C	15	E	27

TABLE F-19a. DATA (MR) AFTER USE OF CALIBRATION LINES

Position	Run 1 t=42.22m	Run 2 t=42.22m	Run 3 t=42.22m	Run 4 t=42.22m
S		271 ± 23.1	241 ± 21.0	284 ± 32.4
E	539 ± 27.1	749 ± 78.7	470 ± 35.1	457 ± 26.7
N	120 ± 3.80	115 ± 3.77	108 ± 3.64	113 ± 3.71
W	74.6 ± 2.40	80.4 ± 2.67	77.5 ± 2.50	76.5 ± 2.56
SE	813 ± 65.6	721 ± 64.5	698 ± 64.2	576 ± 70.4
SW	68.1 ± 2.22	65.6 ± 2.47	64.4 ± 2.12	61.5 ± 2.03
NE	65.1 ± 2.33	63.2 ± 2.42	67.0 ± 2.38	60.3 ± 2.00
NW	65.1 ± 2.24	59.3 ± 1.98	60.3 ± 2.11	52.5 ± 2.16
C		270 ± 21.3	252 ± 22.9	277 ± 23.3

TABLE F-20. RAW DATA

Ground Penetration Floor Flush	PORTION OF AREA II (20"-34") A-2.06 ft^2	1:12 Model S=2.79 Curies

Dosimeter Number	Run 1 Pos.	Run 1 t=49.29m T=50 P=28.60	Run 2 Pos.	Run 2 t=49.29m T=56 P=28.54	Run 3 Pos.	Run 3 t=49.29m T=58.5 P=28.53	Run 4 Pos.	Run 4 t=53.40m T=64 P=28.48
33	E	180	W	82	C	144		
86	S	132	N	60	NE	40	C	161
48	SW	50	E	190	N	60	S	134
70	NW	58	S	107	E	173	NE	40
90	N	61	NW	57	SW	48		
—	C	150	NE	40	NW	58		
134							SE	31
140	SE	32	SE	31.5	SE	32	E	12.5
58	W	89	SW	40	S	116		
63	NE	35	C	145	W	85		

TABLE F-20a. DATA (MR) AFTER USE OF CALIBRATION LINES

Position	Run 1 t=49.29m	Run 2 t=49.29m	Run 3 t=49.29m	Run 4 t=53.40m
S	121 ± 3.97	101 ± 3.21	111 ± 3.59	124 ± 3.94
E	177 ± 5.84	176 ± 5.66	164 ± 5.23	
N	56.8 ± 2.26	54.8 ± 2.12	55.6 ± 1.87	
W	85.2 ± 2.81	80.7 ± 2.88	82.6 ± 2.93	
SE	606 ± 77.8	604 ± 77.8	621 ± 77.9	620 ± 63.4
SW	46.3 ± 1.62	38.3 ± 1.55	44.7 ± 1.98	
NE	34.0 ± 1.78	38.3 ± 1.69	36.5 ± 1.71	37.8 ± 1.39
NW	54.8 ± 1.84	53.0 ± 2.17	55.5 ± 2.09	
C	144 ± 4.67	141 ± 4.66	142 ± 4.68	147 ± 4.80

TABLE F-21. RAW DATA

Floor Flush	AREA I (-20")	1:12 Model
First Floor	A=0.69 ft^2	S=0.227 Curies

Dosimeter Number	Run 1 Pos.	Run 1 t=42.22m T=68 P=28.92	Run 2 Pos.	Run 2 t=42.22m T=70 P=28.89	Run 3 Pos.	Run 3 t=42.22m T=57 P=28.69	Run 4 Pos.	Run 4 t=42.22m T=54 P=28.69
135	S	20	C	22	SE	79	E	56
145	E	49	S	21	C	26	SE	70
48	N	170	SW	162	W	191	NW	128
63	W	182	NE	105	N	155	SW	149
147	SE	66.5	E	66.5	S	24.5	C	22
90	SW	160	NW	126	NE	107	W	182
—	NE	109	N	165	NW	120	N	162
58	NW	122	W	184	SW	155	NE	98
140	C	22.5	SE	69	E	57.5	S	22

TABLE F-21a. DATA (MR) AFTER USE OF CALIBRATION LINES

Position	Run 1 t=42.22	Run 2 t=42.22	Run 3 t=42.22	Run 4 t=42.22
S	361 ± 24.6	375 ± 25.6	441 ± 28.7	397 ± 33.7
E	1110 ± 78.6	1640 ± 85.8	1290 ± 86.1	1280 ± 78.2
N	158 ± 5.03	158 ± 5.14	151 ± 4.97	155 ± 5.04
W	177 ± 5.83	176 ± 5.70	177 ± 5.70	169 ± 5.58
SE	1630 ± 85.6	1630 ± 93.8	1940 ± 96.5	1660 ± 91.0
SW	149 ± 4.91	150 ± 4.79	148 ± 4.77	145 ± 4.78
NE	104 ± 3.45	102 ± 3.47	99.6 ± 3.40	93.8 ± 3.06
NW	117 ± 3.76	117 ± 3.92	115 ± 3.77	119 ± 3.77
C	414 ± 34.0	399 ± 33.7	456 ± 27.2	393 ± 27.9

TABLE F-22. RAW DATA

Floor Flush Basement	AREA I (-20") $A=0.69\ ft^2$	1:12 Model S=0.227 Curies

Dosimeter Number	Run 1 Pos.	t=42.22m T=68 P=28.92	Run 2 Pos.	t=42.22m T=70 P=28.89	Run 3 Pos.	t=42.22m T=57 P=28.69	Run 4 Pos.	t=42.22m T=54 P=28.69
137	S	15.5	C	15.5	SE	44.5	E	30
151	E	29	S	15	C	17	SE	36
28	N	125	SW	74	W	92	NW	59
33	W	96	NE	70	N	125	SW	65
134	SE	35	E	30	S	20	C	
86	SW	85	NW	69	NE	69	W	86
70	NE	74	N	133	NW	69	N	120
39	NW	69	W	99	SW	83	NE	75
144	C	17.5	SE	39	E	30	S	18

TABLE F-22a. DATA (MR) AFTER USE OF CALIBRATION LINES

Position	Run 1 t=42.22m	Run 2 t=42.22m	Run 3 t=42.22m	Run 4 t=42.22m
S	279 $\pm$ 21.6	290 $\pm$ 21.6	389 $\pm$ 25.3	320 $\pm$ 27.0
E	560 $\pm$ 70.2	593 $\pm$ 30.6	549 $\pm$ 76.9	538 $\pm$ 72.7
N	128 $\pm$ 4.23	126 $\pm$ 3.99	123 $\pm$ 4.10	113 $\pm$ 3.60
W	94.5 $\pm$ 3.26	93.5 $\pm$ 2.97	94.0 $\pm$ 3.22	78.6 $\pm$ 2.74
SE	729 $\pm$ 64.6	820 $\pm$ 79.0	948 $\pm$ 76.6	746 $\pm$ 71.8
SW	77.7 $\pm$ 2.71	75.6 $\pm$ 2.71	78.4 $\pm$ 2.52	64.0 $\pm$ 2.44
NE	70.0 $\pm$ 2.27	68.9 $\pm$ 2.57	63.0 $\pm$ 2.32	70.9 $\pm$ 2.29
NW	65.2 $\pm$ 2.13	63.0 $\pm$ 2.32	65.2 $\pm$ 2.14	60.3 $\pm$ 2.32
C	317 $\pm$ 26.9	280 $\pm$ 21.6	322 $\pm$ 22.2	

TABLE F-23. RAW DATA

Floor Flush First Floor			AREA II (20"-160") $A=550\ ft^2$			1:12 Model S=77.84 Curies	
Dosimeter Number	Run 1 Pos.	t=12.92 T=74 P=28.74		Run 2 Pos.	t=11.93 T=78 P=28.72	Run 3 Pos.	t=12.08 T=78 P=28.71
147	S	42		SE	47	E	42
134	W	41		E	39	N	39.5
137	NW	49		W	40	NW	51
135	N	47		SW	48.5	W	42.5
140	E	46.5		C	47	SW	48.5
151	NE	52.5		N	45	SE	48.5
150	SW	52		NE	48	NE	50.5
145	SE	50.5		S	41.5	C	44
144	C	47.5		NW	49	S	41

TABLE F-23a. DATA (R) AFTER USE OF CALIBRATION LINES

Position	Run 1 t=12.92m	Run 2 t=11.93m	Run 3 t=12.08m
S	0.934 ± 0.070	0.930 ± 0.076	0.902 ± 0.080
E	1.04 ± 0.082	0.880 ± 0.066	0.944 ± 0.070
N	1.08 ± 0.074	1.06 ± 0.076	0.890 ± 0.067
W	0.925 ± 0.067	0.866 ± 0.076	0.960 ± 0.072
SE	1.79 ± 0.080	1.09 ± 0.073	1.17 ± 0.078
SW	1.24 ± 0.073	1.14 ± 0.075	1.10 ± 0.083
NE	1.27 ± 0.080	1.14 ± 0.071	1.21 ± 0.073
NW	1.12 ± 0.080	1.13 ± 0.083	1.19 ± 0.080
C	1.08 ± 0.082	1.06 ± 0.082	1.00 ± 0.077

TABLE F-24. RAW DATA

Floor Flush	AREA II (20"-160")	1:12 Model
Basement	A=550 ft^2	S=77.84 Curies

Dosimeter Number	Run 1 Pos.	t=12.92m T=74 P=28.74	Run 2 Pos.	t=11.93m T=78 P=28.72	Run 3 Pos.	t=12.08m T=78 P=28.71
90	SE	51	S	42	E	43
63	S	42	E	39	N	42
58	SW	50	NE	49	SW	49
48	E	45	SW	49	C	63
39	NE	51	W	40	W	41
33	NW	54	N	40	S	40
70	N	45	NW	50	SE	45
—	W	45	SE	48	NE	50
86	C	69	C	62	NW	54

TABLE F-24a. DATA (MR) AFTER USE OF CALIBRATION LINES

Position	Run 1 t=12.92m	Run 2 t=11.93m	Run 3 t=12.08m
S	40.82 $\pm$ 1.91	39.09 $\pm$ 1.87	39.38 $\pm$ 1.89
E	41.71 $\pm$ 1.50	37.91 $\pm$ 1.85	40.01 $\pm$ 1.89
N	42.54 $\pm$ 1.51	39.38 $\pm$ 1.89	40.83 $\pm$ 1.91
W	43.06 $\pm$ 1.79	37.79 $\pm$ 1.37	38.74 $\pm$ 1.40
SE	47.46 $\pm$ 2.04	45.93 $\pm$ 1.86	42.54 $\pm$ 1.51
SW	47.84 $\pm$ 1.78	45.42 $\pm$ 1.59	46.89 $\pm$ 1.76
NE	48.18 $\pm$ 1.65	46.89 $\pm$ 1.76	47.84 $\pm$ 1.90
NW	53.15 $\pm$ 2.18	47.28 $\pm$ 1.63	49.34 $\pm$ 1.99
C	63.04 $\pm$ 2.32	56.65 $\pm$ 2.16	58.40 $\pm$ 1.95

TABLE F-25. RAW DATA

Floor Flush First Floor		AREA III (160"-296") $A=1353$ ft^2			1:12 Model S=77.84 Curies	
Dosimeter Number	Run 1 Pos.	t=16.95m T=76 P=28.44	Run 2 Pos.	t=16.50m T=76 P=28.42	Run 3 Pos.	t=14.60m T=76 P=28.41
90	C	127	NW	116	N	90
63	S	103	NE	117	SW	92
58	N	108	SW	109	NE	97
48	W	109	C	130	S	93
39	NW	120	E	106	W	90
33	SW	111	N	100	SE	99
70	NE	122	SE	119	E	91
—	SE	128	S	102	C	105
86	E	111	W	107	NW	105

TABLE F-25a. DATA (MR) AFTER USE OF CALIBRATION LINES

Position	Run 1 t=16.95m	Run 2 t=16.50m	Run 3 t=14.60m
S	100 ± 3.42	97.6 ± 3.25	86.2 ± 2.76
E	101 ± 3.39	100 ± 3.18	86.0 ± 2.75
N	103 ± 3.35	98.4 ± 3.37	83.7 ± 2.95
W	101 ± 3.22	97.8 ± 3.28	85.0 ± 2.71
SE	122 ± 4.00	113 ± 3.57	97.5 ± 3.34
SW	109 ± 3.69	104 ± 3.38	89.4 ± 3.11
NE	115 ± 3.66	114 ± 3.82	92.8 ± 3.03
NW	113 ± 3.59	108 ± 3.64	95.9 ± 3.23
C	118 ± 3.95	121 ± 3.83	100 ± 3.33

TABLE F-26. RAW DATA

Floor Flush Basement	AREA III (160"-248") A=783 ft^2	1:12 Model S=77.84 Curies

Dosimeter Number	Run 1 Pos.	t=154.6m T=78 P=28.32	Run 2 Pos.	t=189.0m T=58 P=28.69	Run 3 Pos.	t=176.3m T=64 P=28.73
90	SW	6	SW	9.5	C	20
63	E	10	NW	9	NE	7
58	SE	7	C	20	S	12
48	NE	8	W	14	W	11
39	NW	8.5	N	13	SE	9
33	C	18	SE	5	SW	9
70	N	10	E	12.5	NW	8
—	W	11.5	S	15	N	15
86	S	10.5	NE	9.5	E	13

TABLE F-26a. DATA (MR) AFTER USE OF CALIBRATION LINES

Position	Run 1 t=154.6m	Run 2 t=189.0m	Run 3 t=176.3m
S	9.60 ± 1.33	14.4 ± 1.29	11.5 ± 1.08
E	9.71 ± 1.48	11.8 ± 0.852	11.9 ± 1.34
N	9.46 ± 0.823	12.3 ± 0.835	14.4 ± 1.29
W	11.0 ± 1.26	13.0 ± 0.887	10.2 ± 0.852
SE	6.70 ± 1.04	4.92 ± 1.46	8.50 ± 0.791
SW	5.59 ± 1.45	8.84 ± 1.47	8.86 ± 1.48
NE	7.41 ± 0.826	8.68 ± 1.32	6.81 ± 1.47
NW	8.03 ± 0.787	8.75 ± 1.48	7.56 ± 0.805
C	17.7 ± 1.55	19.1 ± 1.17	18.6 ± 1.55

TABLE F-27. RAW DATA

Ground Penetration — AREA I (-20") — 1:12 Model
Floor Elevated — A=0.69 ft^2 — S=0.227 Curies

Dosimeter Number	Run 1 Pos.	Run 1 t=70.37m T=58 P=29.15	Run 2 Pos.	Run 2 t=42.22 T=56 P=28.68	Run 3 Pos.	Run 3 t=42.22 T=56 P=28.67	Run 4 Pos.	Run 4 t=42.22 T=56 P=28.67	Run 5 Pos.	Run 5 t=42.22 T=36 P=29.05
33	N	118	S	175						
58	W	79			C	161	N	80	C	180
48			W	50	N	80	S	184	SW	44
86			SW	45						
70	SW	70	N	90	W	50	C	170	S	180
39	NW	60-1/2	NE	81	S	163	NW	38	W	50
63	NE	129			SW	40	W	50	NE	86
90			NW	40	NE	83	NE	89	NW	39.5
—			C	176	NW	38.5	SW	41	N	80
151					E	55.5	SE	76	E	56.5
134					SE	73.5	E	57	SE	74

TABLE F-27a. DATA (MR) AFTER USE OF CALIBRATION LINES

Position	Run 1 t=70.37m	Run 2 t=42.42m	Run 3 t=42.22m	Run 4 t=42.22m	Run 5 t=42.22m
S		172 ± 5.68	154 ± 4.91	171 ± 5.47	170 ± 5.46
E			1310 ± 80.6	1350 ± 75.4	1260 ± 79.4
N	116 ± 3.89	85.1 ± 2.72	74.2 ± 2.40	76.5 ± 2.56	76.5 ± 2.65
W	75.6 ± 2.53	46.3 ± 1.62	47.3 ± 1.63	48.6 ± 2.07	47.2 ± 1.62
SE			1820 ± 88.6	1900 ± 96.8	1720 ± 85.6
SW	66.2 ± 2.16	41.1 ± 1.80	38.9 ± 1.87	39.2 ± 1.71	40.8 ± 1.47
NE	125 ± 4.17	76.5 ± 2.46	77.2 ± 2.78	82.8 ± 2.93	83.6 ± 2.95
NW	57.2 ± 1.89	37.2 ± 1.84	36.8 ± 1.66	35.9 ± 1.32	36.8 ± 1.83
C		168 ± 5.49	154 ± 4.96	161 ± 5.14	172 ± 5.57

TABLE F-28. RAW DATA

Ground Penetration	PORTION OF AREA II (20"-34")	1:12 Model
Floor Elevated	A=2.06 ft^2	S=2.79 Curies

Dosimeter Number	Run 1 Pos.	Run 1 t=49.29m T=60 P=28.52	Run 2 Pos.	Run 2 t=45.18m T=53 P=28.58	Run 3 Pos.	Run 3 t=53.40m T=60 P=28.53	Run 4 Pos.	Run 4 t=53.40m T=65 P=28.50	Run 5 Pos.	Run 5 t=53.40m T=64 P=28.48
58	N	52	S	109	C	144				
86	W	104	NE	40	SW	58	N	57		
—	NW	59	W	93	S	131	SW	49	N	55
90	SW	55	C	140	W	95	NE	40	SW	51
63	NE	37	N	50	NW	55	S	121	W	87
48	C	151	SW	45	N	60	C	150	NW	55
33	S	121	NW	51			W	81		
134	E	11.3			SE	28.5	SE	36		
140	SE	39	SE	30.7	E	15.5				
70					NE	44	NW	54		
147									E	16.5
144									SE	40

TABLE F-28a. DATA (MR) AFTER USE OF CALIBRATION LINES

Position	Run 1 t=49.29m	Run 2 t=45.18m	Run 3 t=53.40m	Run 4 t=53.40m	Run 5 t=53.40m
S	119 ± 3.98	104 ± 3.38	125 ± 4.09	118 ± 3.93	
E	222 ± 22.6	197 ± 6.38	284 ± 32.1		303 ± 26.3
N	49.8 ± 1.83	48.6 ± 2.07	55.6 ± 1.87	52.1 ± 2.05	52.6 ± 2.02
W	95.0 ± 3.20	89.0 ± 3.00	88.4 ± 3.08	79.7 ± 2.85	84.6 ± 2.98
SE	812 ± 79.3	577 ± 77.6	560 ± 29.5	768 ± 65.1	852 ± 79.3
SW	51.2 ± 2.13	41.7 ± 1.50	53.0 ± 2.07	46.9 ± 1.88	47.5 ± 2.04
NE	36.0 ± 1.82	36.5 ± 1.71	41.6 ± 1.48	37.2 ± 1.84	
NW	56.4 ± 2.11	50.2 ± 2.11	53.5 ± 2.18	51.5 ± 1.74	54.1 ± 2.20
C	140 ± 4.45	130 ± 4.32	138 ± 4.43	139 ± 4.42	

TABLE F-29. RAW DATA

Floor Elevated	AREA I (-20")	1:12 Model
First Floor	$A=0.69\ ft^2$	S=0.227 Curies

Dosimeter Number	Run 1 Pos.	t=35.18m T=59 P=28.86	Run 2 Pos.	t=42.22m T=57 P=28.84	Run 3 Pos.	t=42.22m T=69 P=28.17	Run 4 Pos.	t=42.22m T=72 P=28.17
86	SW	22	C	79	N	40	NW	20
70	NE	60	NW	20	W	28	NE	76
90	W	25	SW	22	NE	80	N	40
63	NW	18	W	24	C	83	SW	20.5
33	N	32	S	79	SW	21	S	99
151	SE	27.5						
145	E	22	E	21	SE	34.5	E	23
134			SE	25.5	E	23.5	SE	28
62			NE	77	NW	19	C	85
47			N	43	S	79.5	W	30

TABLE F-29a. DATA (MR) AFTER USE OF CALIBRATION LINES

Position	Run 1 t=35.18m	Run 2 t=42.22m	Run 3 t=42.22m	Run 4 t=42.22m
S		77.8 ± 2.80	75.1 ± 2.49	97.5 ± 3.34
E	386 ± 25.8	366 ± 25.4	476 ± 27.2	423 ± 26.6
N	31.5 ± 1.74	40.6 ± 1.56	36.5 ± 1.71	37.2 ± 1.84
W	23.3 ± 1.61	23.3 ± 1.62	26.5 ± 1.11	28.4 ± 1.29
SE	520 ± 26.70	493 ± 27.7	732 ± 73.7	571 ± 29.8
SW	20.1 ± 1.13	20.5 ± 1.57	20.7 ± 1.59	19.9 ± 1.57
NE	56.7 ± 1.89	73.0 ± 2.45	74.4 ± 2.70	71.8 ± 2.33
NW	17.5 ± 1.55	18.9 ± 0.961	18.0 ± 1.15	18.3 ± 1.41
C		72.2 ± 2.56	80.7 ± 2.87	80.6 ± 2.67

TABLE F-30. RAW DATA

Floor Elevated Basement	AREA I (-20") $A=0.69\ ft^2$	1:12 Model S=0.227 Curies

Dosimeter Number	Run 1 Pos.	t=35.18m T=59 P=28.86	Run 2 Pos.	t=42.22m T=57 P=28.84	Run 3 Pos.	t=42.22m T=69 P=28.17	Run 4 Pos.	t=42.22m T=72 P=28.17
—	W	143	SW	145	NW	115	N	141
39	NW	94	NE	97	SW	140	W	163
48	N	123	W	170	NE	104	SW	142
58	SW	122	NW	113	N	138	NE	98
28	NE	79.5	N	130	W	150	NW	101
140	E	52	SE	79.5	S	21	SE	76
135	SE	71	S	21	C	17	E	53
138	S	17	E	54	E	53	C	18
137	C	17						
151			C	18	SE	75.5	S	20

TABLE F-30a. DATA (MR) AFTER USE OF CALIBRATION LINES

Position	Run 1 t=35.18m	Run 2 t=42.22	Run 3 t=42.22	Run 4 t=42.22
S	303 ± 31.0	373 ± 24.9	397 ± 33.7	397 ± 23.7
E	1140 ± 83.4	1220 ± 79.8	1260 ± 80.6	1280 ± 78.1
N	114 ± 3.62	133 ± 4.38	132 ± 4.25	135 ± 4.39
W	137 ± 4.45	158 ± 5.03	153 ± 5.03	154 ± 4.91
SE	1710 ± 89.0	1860 ± 101	1980 ± 99.6	1880 ± 101
SW	117 ± 3.76	139 ± 4.51	132 ± 4.19	132 ± 4.18
NE	81.2 ± 2.86	91.6 ± 2.91	96.4 ± 3.07	93.8 ± 3.06
NW	88.8 ± 2.83	108 ± 3.50	110 ± 3.62	103 ± 3.49
C	301 ± 21.9	339 ± 22.5	316 ± 23.9	336 ± 31.6

TABLE F-31. RAW DATA

Floor Elevated	AREA II (20" - 160")	1:12 Model
First Floor	A=550 ft^2	S=77.84 Curies

Dosimeter Number	Run 1 Pos.	t=12.37m T=74 P=28.73	Run 2 Pos.	t=11.98m T=74 P=28.72	Run 3 Pos.	t=12.25m T=73 P=28.71	Run 4 Pos.	t=12.03m T=76 P=28.75
147	NW	49	NW	49.5	C	47	NW	50.5
134	S	42.5	NE	49	N	44.5	W	41.0
137	SW	49.5	SE	49	W	43.5	S	41.5
135	N	45.5	C	49	SW	50.5	N	45.5
140	W	46	E	43	NE	53	SE	49
151	C	49	W	44	SE	51.5	C	49.6
150	NE	50	SW	50.5	S	45	SW	48.5
145	E	44	N	44	NW	50	NE	51
144	SE	49	S	43	E	44	E	43.5

TABLE F-31a. DATA (R) AFTER USE OF CALIBRATION LINES

Position	Run 1 t=12.37m	Run 2 t=11.98m	Run 3 t=12.25m	Run 4 t-12.03m
S	0.969 $\pm$ 0.068	0.951 $\pm$ 0.081	1.04 $\pm$ 0.069	0.903 $\pm$ 0.076
E	0.993 $\pm$ 0.077	0.942 $\pm$ 0.081	0.978 $\pm$ 0.081	0.968 $\pm$ 0.081
N	1.04 $\pm$ 0.073	0.993 $\pm$ 0.077	1.03 $\pm$ 0.069	1.04 $\pm$ 0.073
W	1.02 $\pm$ 0.082	1.02 $\pm$ 0.075	0.956 $\pm$ 0.077	0.928 $\pm$ 0.067
SE	1.12 $\pm$ 0.083	1.12 $\pm$ 0.079	1.24 $\pm$ 0.079	1.11 $\pm$ 0.083
SW	1.13 $\pm$ 0.079	1.20 $\pm$ 0.072	1.18 $\pm$ 0.076	1.15 $\pm$ 0.071
NE	1.19 $\pm$ 0.072	1.16 $\pm$ 0.071	1.21 $\pm$ 0.085	1.20 $\pm$ 0.080
NW	1.14 $\pm$ 0.074	1.16 $\pm$ 0.074	1.16 $\pm$ 0.080	1.19 $\pm$ 0.075
C	1.17 $\pm$ 0.078	1.14 $\pm$ 0.075	1.08 $\pm$ 0.073	1.19 $\pm$ 0.078

TABLE F-32. RAW DATA

Floor Elevated Basement	AREA II (20" - 160") A=550 ft^2	1:12 Model S=77.84 Curies

Dosimeter Number	Pos.	Run 1 t=12.37m T=74 P=28.73	Pos.	Run 2 t=11.98m T=74 P=28.72	Pos.	Run 3 t=12.25m T=73 P=28.71	Pos.	Run 4 t=12.03m T=76 P=28.75
90	W	103	S	94	SW	109	SW	100
63	S	95	W	92	W	100	S	97
58	SW	100	SE	90	C	151	W	95
48	SE	101	E	95	NE	112	NW	112
39	NE	98	SW	96	E	101	E	98
33	N	98	NE	94	S	96	C	145
70	NW	102	NW	109	N	111	N	100
—	E	100	C	140	NW	121	SE	102
86	C	151	N	102	SE	106	NE	106

TABLE F-32a. DATA (MR) AFTER USE OF CALIBRATION LINES

Position	Run 1 t=12.37m	Run 2 t=11.98m	Run 3 t=12.25m	Run 4 t=12.03m
S	92.3 ± 3.20	87.5 ± 3.06	94.5 ± 3.26	94.3 ± 3.25
E	95.7 ± 3.19	88.1 ± 2.82	95.4 ± 3.03	92.6 ± 2.94
N	96.5 ± 3.32	93.2 ± 3.15	105 ± 3.33	94.5 ± 3.01
W	95.9 ± 3.29	89.4 ± 3.11	97.2 ± 3.33	90.9 ± 2.98
SE	93.6 ± 2.99	86.1 ± 2.84	96.9 ± 3.26	97.6 ± 3.25
SW	95.7 ± 3.12	90.7 ± 2.89	101 ± 3.45	93.1 ± 3.21
NE	92.6 ± 2.94	92.5 ± 3.20	104 ± 3.30	96.9 ± 3.26
NW	96.4 ± 3.07	103 ± 3.27	116 ± 3.80	104 ± 3.30
C	138 ± 4.51	134 ± 4.36	144 ± 4.65	143 ± 4.71

TABLE F-33. RAW DATA

Floor Elevated First Floor			AREA III (160"-296") A=1353 ft^2			1:12 Model S=77.84 Curies		
	Run 1		Run 2			Run 3		
Dosimeter Number	Pos.	t=73.9m T=84 P=28.45		Pos.	t=75.1m T=61 P=28.55		Pos.	t=77.0m T=62 P=28.53
147	W	32		E	31.5		NW	35
137	C	34.5		NW	31		NE	32
146	E	33.5		C	36.5		S	34
135	SW	33		N	31.5		C	37
140	NW	35.5		S	33		W	32
151	S	32		SE	34		N	32
150	SE	34		SW	35		E	30.5
149	N	30		W	31		SE	35
144	NE	35.5		NE	35.5		SW	36

TABLE F-33a. DATA (R) AFTER USE OF CALIBRATION LINES

Position	Run 1 t=73.9m	Run 2 t=75.1m	Run 3 t=77.0m
S	0.693 ± 0.071	0.676 ± 0.071	0.688 ± 0.069
E	0.718 ± 0.069	0.602 ± 0.066	0.609 ± 0.072
N	0.617 ± 0.073	0.612 ± 0.078	0.652 ± 0.065
W	0.662 ± 0.067	0.605 ± 0.073	0.651 ± 0.071
SE	0.752 ± 0.065	0.706 ± 0.065	0.720 ± 0.074
SW	0.689 ± 0.078	0.740 ± 0.073	0.733 ± 0.078
NE	0.763 ± 0.078	0.715 ± 0.078	0.613 ± 0.073
NW	0.765 ± 0.079	0.582 ± 0.073	0.708 ± 0.067
C	0.727 ± 0.074	0.758 ± 0.070	0.762 ± 0.079

TABLE F-34. RAW DATA

Floor Elevated Basement	AREA III (160"-296") A=1353 ft^2	1:12 Model S=77.84 Curies

Dosimeter Number	Run 1 Pos.	t=73.9 T=84 P=28.45	Run 2 Pos.	t=75.1 T=61 P=28.55	Run 3 Pos.	t=77.0 T=62 P=28.53
90	SW	18	SE	21	N	30
63	NE	17	C	45	NW	18
58	S	28	N	29	E	29
48	NW	19	SW	19	SE	20
39	N	30	E	29	C	49
33	C	45	NE	18	SW	20
70	E	25	W	29	S	30
—	W	29	S	30	NE	19
86	SE	18	NW	20	W	30

TABLE F-34a. DATA (MR) AFTER USE OF CALIBRATION LINES

Position	Run 1 t=73.9m	Run 2 t=75.1m	Run 3 t=77.0m
S	26.8 ± 1.31	28.7 ± 1.50	28.4 ± 1.16
E	23.6 ± 1.05	27.4 ± 1.12	27.7 ± 1.32
N	28.3 ± 1.14	27.7 ± 1.32	27.9 ± 1.67
W	27.7 ± 1.48	27.4 ± 1.14	27.4 ± 1.54
SE	16.4 ± 1.39	19.5 ± 1.56	18.5 ± 0.973
SW	16.7 ± 1.53	17.6 ± 0.957	19.7 ± 1.58
NE	16.5 ± 1.54	17.7 ± 1.55	18.2 ± 1.34
NW	17.6 ± 0.957	18.3 ± 1.41	17.5 ± 1.55
C	44.3 ± 1.99	43.7 ± 1.97	46.3 ± 1.59

APPENDIX G

COMPUTER PROGRAMS

The computer programs in this section were coded in Fortran IV for use on the IBM 1401-1410 computer located on the campus of Kansas State University. Preceding each program is an explanation of the terms used in that program. The reader is cautioned that a variable in one program may or may not be designated by the same symbol in another. Below is a summary of the programs used:

1. Dosimeter Data - Normalizes data to 22^{0} C and 760 mm Hg.
2. Linear Regression I - Determines a calibration line through the data using the least squares method.
3. Linear Regression II - Determines a calibration line which passes through the origin using the least squares method on the data.
4. Data Interpretation I - Uses calibration lines to calculate actual dose rates from experimental data from 10 mr dosimeters; also gives standard deviation associated with each dose rate.
5. Data Interpretation II - Performs same function as number 4 but treats data from 200 mr dosimeters.
6. Data Interpretation III - Interprets data from 2 r dosimeters which lie to the right of the intersection of the two lines making up the calibration curve for each 2 r dosimeter; also calculates standard deviations.
7. Data Interpretation IV - Same as number 6 but treats 2 r data to the left of the intersection of the two lines.
8. Data Normalization - Normalizes data to r/hr per curie/ft^2 and gives resultant standard deviations.

1. Dosimeter Data

NOEXP	Number of experiments
NPTEXP	Number of runs per experiment
D	Measured dose
T	Temperature in ^{o}F
P	Pressure in inches of Hg
TIME	Run time in hours
BETA	Factor for normalizing data to 22^{o} C and 760 mm Hg

```
C     CORRECTIONS FOR TEMP. AND PRESS., DETERMINATION OF AVERAGE READING
      DIMENSIOND(51),T(51),P(51),TIME(51),AVGDOS(51)
  200 FORMAT(10I3)
  201 FORMAT(8F10.6)
  202 FORMAT( 20X,F10.6,4X,F6.2)
  203 FORMAT( 10X,6F10.6,/)
  204 FORMAT(6HLBETA=,F10.6)
  500 READ(1,200)NOEXP
      DO220J=1,NOEXP
      READ(1,200)NPTEXP
      IF(NPTEXP.EQ.0) CALL EXIT
      READ(1,201)(D(I),I=1,NPTEXP)
      READ(1,201)(T(I),I=1,NPTEXP)
      READ(1,201)(P(I),I=1,NPTEXP)
      READ(1,201)TIME(J)
      XP=NPTEXP
      AVGDOS(J)=0.0
      DO218K=1,NPTEXP
      BETA=((273.+.555*(T(K)-32.))*760.)/(295.*25.401*P(K))
      WRITE(3,204) BETA
      D(K)=BETA*D(K)
  218 AVGDOS(J)=AVGDOS(J)+(D(K)/XP)
      WRITE(3,203)(D(K),K=1,NPTEXP)
      WRITE(2,203)(D(K),K=1,NPTEXP)
  220 CONTINUE
      DO221I=1,NOEXP
  221 WRITE(3,202)AVGDOS(I),TIME(I)
      GO TO 500
      END
```

2. Linear Regression I

MODE	Number of sets of data (one set for each dosimeter)
N1	Number of data points on first card
N2	Sum of the number of data points on the first and second cards
N3	Sum of the number of data points on the first three cards
NY	Total number of (x,y) values in each set of data
T	Value of Student's t
X	Calculated dose rate
Y	Experimentally determined dose rate

The remaining terms are described by the following equation which was used on page 43 in Appendix C.

XAVE + ($\bar{Y}$ - YINT)/SLOPE $\pm$ TOVB * SQRT (SIGMA2 + (0.03 * $\bar{Y}$) ** 2)

* SQRT (1.0 + BUNK + ($\bar{Y}$ - YINT) ** 2/SIGMAD) =

$$\bar{X} + \frac{\bar{y} - a}{b} \pm \frac{t[s^2 + (0.03\bar{y})^2]^{.5}}{b}\left[\left(\frac{1}{m} + \frac{1}{k}\right) + \frac{(\bar{y} - a)^2}{b^2 \sum(x_i - \bar{x})^2}\right]^{1/2}$$

```
C       LINEAR REGRESSION ANALYSIS FOR STRAIGHT LINE
        DIMENSION X(35),Y(35)
 100    FORMAT(4I3,F10.5)
 101    FORMAT( 10X,6F10.6)
 102    FORMAT(/,5X,F10.6,5X,F10.6,5X,F10.6,5X,F10.6,5X,F10.6,5X,F15.9,5X,
       1F10,6)
 103    FORMAT(I3,3F18.15)
 104    FORMAT( 10X,4HX = ,F11.6,4H+OR-,F11,6     )
 105    FORMAT( 8F10.2)
 106    FORMAT(2I3)
 107    FORMAT( 10X,4F10.6)
 230    FORMAT(5F10.6,F15.9)
  99    FORMAT(83HX= XAVE + (Y - YINT)/SLOPE +OR- TOVB*SPRIME(1/M + BUNK +
       1 (Y - YINT)**2/ SIGMAD)**,5)
  98    FORMAT(//,5X,4HXAVE,11X,4HYINT,11X,5HSLOPE,10X,4HTOVB,11X,4HBUNK,1
```

```
     11X,6HSIGMAD,14X,6HSIGMA1)
204  READ(1,100)MODE
     IF(MODE.GT.0) GO TO  203
     SUMX=0.
     SUMY=0.
     SUMXY=0.
     SUMY2=0.
     SUMX2=0.
     READ(1,100)N1,N2,N3,NY,T
     N11=N1+1
     N22=N2+1
     N33=N3+1

     READ(1,101)  (X(I),I=1,N1)
     READ(1,101)  (X(J),J=N11,N2)
     READ(1,101)  (X(K),K=N22,N3)
     READ(1,101)  (X(L),L=N33,NY)
     READ(1,101)  (Y(I),I=1,N1)
     READ(1,101)  (Y(J),J=N11,N2)
     READ(1,101)  (Y(K),K=N22,N3)
     READ(1,101)  (Y(L),L=N33,NY)
  11 DO200I=1,NY
     SUMX=SUMX+X(I)
     SUMY=SUMY+Y(I)
     SUMXY=SUMXY+ X(I)*Y(I)

     SUMY2=SUMY2+Y(I)*Y(I)
200  SUMX2=SUMX2+X(I)*X(I)
     FY=NY
     BUNK=1./FY
     SLOPE=(SUMXY-SUMX*SUMY/FY)/(SUMX2-SUMX**2/FY)
     XAVE=SUMX/FY
     YINT=SUMY/FY
     SIGMAD=SLOPE**2*(SUMX2-SUMX**2/FY)
     SIGMA2=(SUMY2-SUMY**2/FY-SLOPE**2*(SUMX2-SUMX**2/FY))/(FY-2.)
     SIGMA1=SQRT(SIGMA2)
     TOVB=T/SLOPE
     WRITE(3,99)

     WRITE(3,98)
     WRITE(3,102)XAVE,YINT,SLOPE,TOVB,BUNK,SIGMAD,SIGMA1
     WRITE(2,200)XAVE,YINT,SLOPE,TOVB,BUNK,SIGMAD
     GO TO 204
203  IF(MODE.EQ.1)CALL EXIT
     END
```

3. Linear Regression II

The following equation defines the terms that were either changed or not used in the preceding program:

$$\overline{Y}/\text{SLOPE} \pm \text{SIGMA} * \text{SQRT}\ (1.0 + \text{SIGMA1} * \overline{Y} ** 2) =$$

$$\frac{y}{b} \pm \frac{ts}{b}\left[\frac{1}{m} + \frac{\overline{y}^2}{b^2 \sum (x_i)^2}\right]^{1/2}$$

NOTE: The constant percentage error in the x values due to the standard deviation associated with the calibration source strength was included in the error term above by hand.

```
C     LINEAR REGRESSION ANALYSIS FOR STRAIGHT LINE THRU ORIGIN
      DIMENSION X(40),Y(40),TIME(40)
 100  FORMAT( I3,F10.5)
 101  FORMAT( 10X,3F10.6)
 102  FORMAT( 10X,6HX = Y/,F11.6,4H+OR-,F10.8,8H(1/M+Y2*F18.15,1H))
 103  FORMAT(I3,3F18.15)
 104  FORMAT( 10X,4HX = ,F11.6,4H+OR-,F11.6     )
 105  FORMAT( 3F10.6)

 106  FORMAT( 10X,F11.6,F11.8,F18.15)
 204  READ(1,100)MODE
      IF(MODE.GT.0) GO TO  203
      SUMXY=0.
      SUMY2=0.
      SUMX2=0.
      READ(1,100)NY,T
      XN=NY
      READ(1,101)  (X(I),I=1,NY)
      READ(1,105)  (Y(I),I=1,NY)
      DO 200 I=1,NY
      SUMXY=SUMXY+ X(1)*Y(I)

      SUMY2=SUMY2+Y(I)*Y(I)
 200  SUMX2=SUMX2+X(I)*X(I)
      SLOPE=SUMXY/SUMX2
      RAT=(SUMY2-((SUMXY*SUMXY)/SUMX2))/(XN -1.)
      SIGMA=(SQRT(RAT)*T)/SLOPE
      SIGMA1=1./(SLOPE*SLOPE*SUMX2)
      WRITE(3,102)SLOPE,SIGMA,SIGMA1
      WRITE(2,106)SLOPE,RAT,SIGMA1
      GO TO 204
 203  IF(MODE.EQ.1)CALL EXIT
      END
```

4. Data Interpretation I

NOEXP	Total number of sets of data
NPTS	The number of repetitions of an experiment
L	Dosimeter number
SET	The number of the set of data
X(L)	A calculated dose rate for a particular dosimeter
Y(L)	An experimentally determined dose rate for a given dosimeter
SIGMA	The standard deviation associated with each data point

```
C      INTERPRETATION OF DATA FROM 10  MR DOSIMETERS
       DIMENSION Y(250)
  108 FORMAT(2I3)
  110 FORMAT(10X,5F10.6)
  112 FORMAT(/,10X,1HX,I3,3H = ,F10.6,5X,7H+ OR - ,F10.6,5X,9HDATA SET ,
     1I3)
 1000 READ(1,108)NOEXP
       IF(NOEXP.EQ.0)CALLEXIT
       DO400J=1,NOEXP
       READ(1,108)NPTS
       READ(1,108)L,SET

       READ(1,110)(Y(I),I=1,NPTS)
       DO300I=1,NPTS
       IF(L.EQ.172)GOTO10
       IF(L.EQ.168)GOTO20
       IF(L.EQ.165)GOTO30
       IF(L.EQ.176)GOTO40
       IF(L.EQ.162)GOTO50
       IF(L.EQ.167)GOTO60
       IF(L.EQ.160)GOTO70
       IF(L.EQ.166)GOTO80
       IF(L.EQ.161)GOTO90
   10 X172= Y(I)/11.334285

       SIGMA=(1.01/11.334285)*SQRT(1.69598+(.05*Y(I))**2)*SQRT(1.+.000015
     1570462964*Y(I)**2)
       WRITE(3,112)L,X172,SIGMA,SET
       GOTO300
   20 X168= Y(I)/ 11.316036
       SIGMA=(1.01/11.316036)*SQRT(1.36874+(.05*Y(I))**2)*SQRT(1.+.000011
     158669821*Y(I)**2)
       WRITE(3,112)L,X168,SIGMA,SET
       GOTO300
```

```
30 X165= Y(I)/11.269712
   SIGMA=(1.01/11.269712)*SQRT(1.63169+(.05*Y(I))**2)*SQRT(1.+.000011
  1682146361*Y(I)**2)
   WRITE(3,112)L,X165,SIGMA,SET
   GOTO300
40 X176= Y(I)/11.462611
   SIGMA=(1.01/11.462611)*SQRT(2.33798+(.05*Y(I))**2)*SQRT(1.+.000011
  1292268393*Y(I)**2)
   WRITE(3,112)L,X176,SIGMA,SET
   GOTO300
50 X162= Y(I)/11.672009
   SIGMA=(1.01/11.672009)*SQRT(1.07409+(.05*Y(I))**2)*SQRT(1.+.000014
  1682449470*Y(I)**2)
   WRITE(3,112)L,X162,SIGMA,SET
   GOTO300
60 X167= Y(I)/11.502398
   SIGMA=(1.01/11.502398)*SQRT(2.55768+(.05*Y(I))**2)*SQRT(1.+.000011
  1214283768*Y(I)**2)
   WRITE(3,112)L,X167,SIGMA,SET
   GOTO300
70 X160= Y(I)/11.408569
   SIGMA=(1.01/11.408569)*SQRT(3.01494+(.05*Y(I))**2)*SQRT(1.+.000011
  1399504586*Y(I)**2)
   WRITE(3,112)L,X160,SIGMA,SET
   GOTO300
80 X166= Y(I)/11.617152
   SIGMA=(1.01/11.617152)*SQRT(1.73806+(.05*Y(I))**2)*SQRT(1.+.000010

  1993828150*Y(I)**2)
   WRITE(3,112)L,X166,SIGMA,SET
   GOTO300
90 X161= Y(I)/11.516460
   SIGMA=(1.01/11.516460)*SQRT(1.54245+(.05*Y(I))**2)*SQRT(1.+.000011
  1186913951*Y(I)**2)
   WRITE(3,112)L,X161,SIGMA,SET
   GOTO300
300 CONTINUE
400 CONTINUE
   GOTO1000
   END
```

5. Data Interpretation II

The meaning of the terms in this program are the same as in program 4.

```
      DIMENSION Y(10)
  108 FORMAT(2I3)
  109 FORMAT(5F10.6)
  112 FORMAT(/,10X,1HX,I3,3H = ,F10.6,5X,7H+ OR - ,F10.6,5X,9HDATA SET ,
     1I3)
C     INTERPRETATION OF DATA FROM 200 MW DOSIMETERS
 1000 READ(1,108)NOEXP
      IF(NOEXP.EQ.0)CALLEXIT
      DO400J=1,NOEXP
      READ(1,108)NPTS
      READ(1,108)L,SET
      READ(1,109)(Y(I),I=1,NPTS)
      DO300I=1,NPTS
      IF(L.EQ.90)GOTO10
      IF(L.EQ.63)GOTO20
      IF(L.EQ.58)GOTO30
      IF(L.EQ.28)GOTO40
      IF(L.EQ.48)GOTO50
      IF(L.EQ.39)GOTO60
      IF(L.EQ.62)GOTO70
      IF(L.EQ.33)GOTO80
      IF(L.EQ.70)GOTO90
      IF(L.EQ.76)GOTO110
      IF(L.EQ.00)GOTO130
      IF(L.EQ.86)GOTO150
      IF(L.EQ.47)GOTO160
   10 X90=Y(I)/1.161257
      SIGMA=(1.01/1.161257)*SQRT(2.35794+(.03*Y(I))**2)*SQRT(1.+.0000028
     160398042*Y(I)**2)
      WRITE(3,112)L,X90,SIGMA,SET
      GOTO300
   20 X63=Y(I)/1.111735
      SIGMA=(1.01/1.111735)*SQRT(2.18372+(.03*Y(I))**2)*SQRT(1.+.0000031
     120794501*Y(I)**2)
      WRITE(3,112)L,X63,SIGMA,SET
      GOTO300
   30 X58=Y(I)/1.129400
      SIGMA=(1.01/1.129400)*SQRT(1.11626+(.03*Y(I))**2)*SQRT(1.+.0000030
     123934649*Y(I)**2)
      WRITE(3,112)L,X58,SIGMA,SET
      GOTO300
   40 X28=Y(I)/1.057666
      SIGMA=(1.01/1.057666)*SQRT(1.84394+(.03*Y(I))**2)*SQRT(1.+.0000034
     148025492*Y(I)**2)
```

```
      WRITE(3,112)L,X28,SIGMA,SET
      GOTO300
   50 X48=Y(I)/1.165804
      SIGMA=(1.01/1.165804)*SQRT( .72077+(.03*Y(I))**2)*SQRT(1.+.0000028
     138026652*Y(I)**2)

      WRITE(3,112)L,X48,SIGMA,SET
      GOTO300
   60 X39=Y(I)/1.143706
      SIGMA=(1.01/1.143706)*SQRT( .61450+(.03*Y(I))**2)*SQRT(1.+.0000029
     148756310*Y(I)**2)
      WRITE(3,112)L,X39,SIGMA,SET
      GOTO300
   70 X62=Y(I)/1.139273
      SIGMA=(1.01/1.139273)*SQRT(1.10707+(.03*Y(I))**2)*SQRT(1.+.0000029
     171748630*Y(I)**2)
      WRITE(3,112)L,X62,SIGMA,SET
      GOTO300

   80 X33=Y(I)/1.097697
      SIGMA=(1.01/1.097697)*SQRT(2.14660+(.03*Y(I))**2)*SQRT(1.+.0000032
     101124866*Y(I)**2)
      WRITE(3,112)L,X33,SIGMA,SET
      GOTO300
   90 X70=Y(I)/1.142967
      SIGMA=(1.01/1.142967)*SQRT( .65345+(.03*Y(I))**2)*SQRT(1.+.0000029
     152569826*Y(I)**2)
      WRITE(3,112)L,X70,SIGMA,SET
      GOTO300
  110 X78=Y(I)/1.176685
      SIGMA=(1.01/1.176685)*SQRT(6.37369+(.03*Y(I))**2)*SQRT(1.+.0000027

     185784711*Y(I)**2)
      WRITE(3,112)L,X78,SIGMA,SET
      GOTO300
  130 X00=Y(I)/1.129333
      SIGMA=(1.01/1.129333)*SQRT(1.59028+(.03*Y(I))**2)*SQRT(1.+.0000030
     124294283*Y(I)**2)
      WRITE(3,112)L,X00,SIGMA,SET
      GOTO300
  150 X86=Y(I)/1.182663
      SIGMA=(1.01/1.182663)*SQRT(1.96913+(.03*Y(I))**2)*SQRT(1.+.0000027
     157694084*Y(I)**2)
      WRITE(3,112)L,X86,SIGMA,SET

      GOTO300
  160 X47=Y(I)/1.143370
      SIGMA=(1.01/1.143370)*SQRT(1.00434+(.03*Y(I))**2)*SQRT(1.+.0000029
     150488846*Y(I)**2)
      WRITE(3,112)L,X47,SIGMA,SET
  300 CONTINUE
  400 CONTINUE
      GOTO1000
      END
```

6. Data Interpretation III

The meaning of the terms in this program are given by the equation in program 2.

```
      DIMENSION Y(10)
  108 FORMAT(2I3)
  110 FORMAT(5F10.6)
  112 FORMAT(/,10X,1HX,I3,3H = ,F10.6,5X,7H+ OR - ,F10.6,5X,9HDATA SET ,
     1I3)
  114 FORMAT(5F10.6,F15.9,F10.6)
C     INTERPRETATION OF DATA FROM 2 R DOSIMETERS
 1000 READ(1,108)NOEXP
      IF(NOEXP.EQ.0)CALLEXIT
      DO400J=1,NOEXP
      READ(1,108)NPTS
      READ(1,108)L,SET
      READ(1,110)(Y(I),I=1,NPTS)
      READ(1,114)XAVE,YINT,SLOPE,TOVB,BUNK,SIGMAD,SIGMA2
      DO300I=1,NPTS
      X=XAVE+(Y(I)-YINT)/SLOPE
      SIGMA=TOVB*SQRT(SIGMA2+(.03*Y(I))**2)*SQRT(1.+BUNK+(Y(I)-YINT)**2/
     1SIGMAD)
      WRITE(3,112)L,X,SIGMA,SET
  300 CONTINUE
  400 CONTINUE
      GOTO1000
      END
```

7. Data Interpretation IV

The terms here have the same meaning as elsewhere except for SIGMAD, which in this program is equal to SIGMA1 in program 3 and is equal to $\frac{1}{\text{SIGMAD}}$ in program 2.

```
      DIMENSION Y(10)
  108 FORMAT(2I3)
  110 FORMAT(5F10.6)
  112 FORMAT(/,10X,1HX,I3,3H = ,F10.6,5X,7H+ OR - ,F10.6,5X,9HDATA SET ,
     1I3)
  114 FORMAT(10X,F11.6,F11.6,F18.15,F10.6)
C     INTERPRETATION OF DATA FROM 2 R DOSIMETERS (PORTION THRU ORIGIN)
 1000 READ(1,108)NOEXP
```

```
      IF(NOEXP.EQ.0)CALLEXIT
      DO400J=1,NOEXP
      READ(1,108)NPTS
      READ(1,108)L,SET
      READ(1,110)(Y(I),I=1,NPTS)
      READ(1,114)SLOPE,SIGMA2,SIGMAD,TOVB
      DO300I=1,NPTS
      X=Y(I)/SLOPE
      SIGMA=TOVB*SQRT(SIGMA2+(.03*Y(I))**2)*SQRT(1.+SIGMAD*(Y(I)**2))
      WRITE(3,112)L,X,SIGMA,SET
  300 CONTINUE
  400 CONTINUE
      GOTO1000
      END
```

8. Data Normalization

NOEXP	The total number of sets of data (34)
M	The number of the set of data
NE	The number of detector locations
NPTS	The number of repetitions of the experiment
CURIES	Source strength in curies
SIGMAC	Error term associated with the source strength (%)
D	Dose rate (mr/hr)
S	Error associated with the dose rate (mr/hr)
SIGMAD	Error associated with the dose rate (%)
F	Normalization factor
DOS	Normalized dose rate (mr/hr per curie/ft^2)
SIG	Error associated with the normalized dose rate (mr/hr per curie/ft^2)
AVEDOS	Normalized, averaged dose rate for a particular detector position
SIGMA1	The normalized, averaged standard deviation associated with AVEDOS

```
      DIMENSION D(5),SIGMAD(5),TIME(5),F(5),DOS(5),SIG(5),AREA(5),S(5)
   98 FORMAT(25X,8HAVEDOS= ,F11.6)
   99 FORMAT(/,25X,7HSIGMA= ,F10.6,//)
  100 FORMAT(I3)
  101 FORMAT(5F10.6)
  103 FORMAT(10X,6F12.5,/)
  104 FORMAT(5F12.5)
  105 FORMAT(5X,9HDATA SET ,I3)
C     DATA NORMALIZATION TO R/HR/(CURIE/FT2)
      READ(1,100)NOEXP
      IF(NOEXP.EQ.0)CALL EXIT
      DO 230 J=1,NOEXP

      READ(1,100)M
      READ(1,100)NE
      READ(1,100)NPTS
      READ(1,101)(TIME(I),I=1,NPTS)
      READ(1,101)(AREA(I),I=1,NPTS)
      READ(1,101)CURIES,SIGMAC
      PTS=NPTS
      DO 208 N=1,NE
      READ(1,101)(D(I),I=1,NPTS)
      READ(1,101)(S(I),I=1,NPTS)
      DO 220 K=1,NPTS
      F(K)=AREA(K)/(CURIES*TIME(K)/60.)

      DOS(K)=F(K)*D(K)
      SIGMAD(K)=S(K)/D(K)
      SIG(K)=DOS(K)*SQRT(SIGMAD(K)**2 + SIGMAC**2)
      IF(D(K).NE.0.) GO TO 220
      SIG(K)=0.
      DOS(K)=0.
  220 CONTINUE
      SUMDOS=0.
      SIGMA2=0.
      DO 180 L=1,NPTS
      SIGMA2=SIGMA2 + SIG(L)**2
  180 SUMDOS=SUMDOS+DOS(L)

      AVEDOS=SUMDOS/PTS
      SIGMA1=(SQRT(SIGMA2))/PTS
      WRITE(3,105)M
      WRITE(3,103)(F(K),K=1,NPTS)
      WRITE(3,103)(DOS(K),K=1,NPTS)
      WRITE(3,103)(SIG(K),K=1,NPTS)
      WRITE(3,98)AVEDOS
      WRITE(3,99)SIGMA1
      WRITE(2,104)(DOS(K),K=1,NPTS)
  208 CONTINUE
  230 CONTINUE
      END
```

EXPERIMENTAL DETERMINATION OF THE PROTECTION FACTORS OF 1:12 AND 1:4 MODELS OF THE KSUNESF BLOCK HOUSE

by

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ABSTRACT

An experimental study has been made to determine the radiation intensity from surrounding fallout at various positions in a 1:12 and a 1:4 scale, steel model of a concrete block house with a basement. The plane fallout field was simulated by pumping an 80-curie cobalt-60 source at a constant speed through plastic tubing laid so as to maintain a constant tubing length per unit surface area. Total dose measurements were made using ion chambers. A unique feature of the two models was that each could be adapted to simulate a block house with a portion of its basement walls exposed.

The inverse of the factor by which the radiation intensity is reduced at a point is called the protection factor at that point. With the aid of a method developed by Kaplan, et. al. the experimental data were analyzed and protection factors were calculated for locations at the sides, corners, and center of each model. The results for the two models agreed within their standard deviations in every location except the corners of the basement. A comparison was also made among the model protection factors, those calculated using standard computational methods, and the results obtained for the full-scale building.